Uncertainty in monitoring salt-marsh accretion on various spatial scales

de Groot, A.V.; Bakker, J.P.; Veeneklaas, R.M.; Kuijper, D.P.J.

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12th

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SYMPOSIUM

SCIENCE FOR NATURE CONSERVATION AND MANAGEMENT

THE WADDEN SEA ECOSYSTEM AND EU DIRECTIVES

Proceedings of the 12th International Scientific Wadden Sea Symposium, 30 March – 3 April 2009 in Wilhelmshaven, Germany

WADDEN SEA ECOSYSTEM No. 26 – 2010

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Editors
Harald Marencic, Common Wadden Sea Secretariat (CWSS)
Kai Eskildsen, Wadden Sea National Park of Schleswig-Holstein,
Hubert Farke, Wadden Sea National Park of Lower Saxony,
Stefanie Hedtkamp, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

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Common Wadden Sea Secretariat

Contents

Foreword

Wadden Sea conservation across borders – how to get it fit for the future

At the end of the 12th International Scientific Wadden Sea Symposium in Wilhelmshaven, the over 270 participants underlined the importance of closer cooperation on the protection of the Wadden Sea.

The symposium resulted in clear recommendations for the decision makers in policy. The recommendations are to be taken into consideration in the preparation of the next Trilateral Governmental Conference on Sylt in March 2010.

The symposium was organized by the German Ministry for the Environment, Nature Conservation and Nuclear, Safety, the National Park Administrations (Niedersachsen, Hamburg, Schleswig-Holstein Wadden Sea), and the Common Wadden Sea Secretariat (CWSS).

Since 1975, when the first symposium was held, global changes have occurred which have affected the Wadden Sea as a marine habitat of international importance significantly. Climate change and the subsequent changes in species composition are regarded as important issues which have to be dealt with by science and policy A main demand by the researchers is therefore to increase the resilience of the ecosystem. Management should aim to restore natural dynamics and geomorphological conditions in the Wadden Sea in order to allow the system to better adapt to accelerated sea level rise.

Another important topic of the sympsoium are various EU Directives, which are relevant for the protection of the Wadden Sea. The further harmonization between the Wadden Sea regions were adressed at several presentations.

An important milestone of international cooperation is the "Memorandum of Understanding" which was signed between the Korean Ministry of Land, Transport and Maritime Affairs and the Trilateral Wadden Sea Cooperation at the symposium. It provides a basis for a cooperation of tidal flat experts of these states. Korea has a tidal flat area with similar functions as the Wadden Sea and the cooperation has the aim to exchange knowledge and experiences between the two regions.

The results of scientific research over the last 30 years have considerably contributed to support the desgnation of the Wadden Sea as World Heritage Site in June 2009.

We would like to thank all who have contributed to this successful symposium and provided valuable support for Wadden Sea research and mangement.

The Editors

Recomendations from the

12th International Scientific Wadden Sea Symposium

Wilhelmshaven, 30 March – 3 April 2009

General Preamble

Nature conservation and management in the Wadden Sea should, as formulated in the trilateral Guiding Principle, aim "to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way". Much has already been achieved in recent decades but the Wadden Sea is still facing issues of concern such as retarded recovery of biological diversity, the loss of salt marshes, and ongoing contamination with new chemical substances. There is also the need to develop strategies to deal with the consequences of global developments such as climate change and invasive alien species. Finally, in terms of policy and management, there is an increasingly complex system of international, European and national legal instruments and agreements which can both lead to confusion and/or work at cross-purposes. Therefore, there is an urgent need for a better integration in research, monitoring and management with timely involvement and participation of all stakeholders (researchers from various disciplines, government agencies, NGOs and other sectors). A similar holistic and integrative approach should be applied when exploring possibilities for EU-funding.

The Twelfth International Scientific Wadden Sea Symposium discussed these issues under the title 'Science for Nature Conservation and Management'. Given that the trilateral Wadden Sea Cooperation serves as an example in the wider European or even global context, the symposium considered the following recommendations to be of strategic importance for the three Wadden Governments.

Recommendations to the Trilateral Governmental Conference

1. Develop one comprehensive scheme for the conservation and sustainable development of the trilateral Wadden Sea in order to implement the various EU Directives more effectively. Such a scheme will serve as an example for the wider EU. In this context it is important that:
    a. The trilateral Wadden Sea is considered as a sub-region according to the Marine Strategy Framework Directive and
    b. the definitions of "Good Ecological Status / Favourable Conservation Status / Good Environmental Status" as respectively required by the Water Framework Directive / Habitats and Species Directive and the Marine Strategy Framework Directive have to be harmonised to ensure that also the implementation of these Directives is harmonised.
    c. the Ecosystem Approach should be applied to Wadden Sea policy and management.
    d. we must build on existing trilateral structures, agreements and instruments, including monitoring and data handling.
2. Extend the trilateral cooperation area by adding the adjacent off-shore conservation areas, because there is a strong relationship between the Wadden Sea and these areas and treat the inshore and near offshore areas as a single system.

3. The monitoring efforts of the trilateral area should not be restricted to the minimum requirements resulting from the Natura2000, Water and Marine Strategy Framework Directives as these do not provide sufficient information for a proper and scientifically sound ecosystem management of the Wadden Sea. Accordingly, the TMAP should be expanded to develop trilateral strategies and methodologies for monitoring and assessing the ecological values of in particular the subtidal area. Furthermore, a large effort should be given to the development of conservation objectives which underpin the whole management process.
4. Where necessary and possible restore the natural structure and functioning both to increase resilience to the impacts of accelerating sea level rise and to enhance sustainable economic development, taking due account of geo-morphological conditions.
5. The natural landscape of the Wadden Sea and the cultural landscape of the adjacent land area must be regarded as complementary parts of the same landscape. Therefore cooperation between the cultural and environmental heritage should be improved.
6. Governments need to join and reinforce ongoing international efforts to prevent alien species introductions and develop an alien species management strategy for the Wadden Sea.

The relevance of science for management and policy: the Korean experience

[1]C.H. Koh, [1]B.O. Kwon, [2]G.H. Yuk, [3]J.S. Ryu, [2,*]W.K. Chang, [4]J.S. Khim
[1]Seoul National University, Seoul, Korea; [2]Korea Maritime Institute, Seoul, Korea;
[3]University of Washington, Seattle, WA, USA; [4]Korea University, Seoul, Korea,
wkchang@kmi.re.kr

1. Introduction

The Korean tidal flat has two historically interesting features: 1) a large scale reclamation of tidal flats for human land use, either completed or continuing and planned since the 1980s; and 2) an intensive, sustainable and long-standing use of tidal flats by fishermen for economic purposes. In fact, for several decades the Korean tidal flat has suffered political and social tensions caused by conflicting 'development' and 'conservation' interests. During the last century, nearly half of the valuable wetlands in the Korean tidal flat were converted into drylands by reclamation. But, after a couple of recent bad experiences with reclamation projects, notably Shihwa and Saemangeum, people realized the value of natural ecosystem services provided by the Korean tidal flats, Finally the Korean government started to lean towards conservation policies for the tidal flats. Some good examples of this change are 1) designating the Coastal Wetlands Protected Areas (CWPAs); and 2) launching the wetlands restoration projects nationwide.

The conservation policy is currently supported by both the government and citizens of Korea. However, over the short period that conservation policy has been adopted, it seems that little scientific knowledge has been incorporated into the decision-making process. For example, during the designation process of CWPAs in Korea, political and social issues were highly influential in screening, site selection and implementation decisions, while ecological considerations took a back seat. Although the social issues were critical and essential for the successful management of CWPAs, the political and social demands for the protected areas could compromise the biological issues, thus impairing the integrity of the ecosystem itself (Allison et al., 1998).

There is an increasing demand for, and adoption of science-based environmental management at local, regional, national, and international levels (Gutrich et al., 2005). For example, the Wadden Sea policies rely heavily on scientific knowledge to provide a basis for decisions regarding conservation and management. Experts in the fields of social and natural sciences are involved not only in determining and monitoring the natural values of the Wadden Sea, but also in determining the effects of human activities on these ecosystems during the policy evaluation process (Turnhout et al., 2007). Furthermore, since the 3rd International Scientific Wadden Sea Symposium in 1981, the outcomes of recommendations from the symposia serve as inputs in the trilateral conferences, indicating a science based policy-making process (Ter Steege and van der Windt, 1994).

This study will focus on how the scientific effort and outcome has been incorporated into the decision-making process and subsequent management practice on the Korean tidal flats. To aid a better understanding, the ecological and social aspects of the Korean tidal flats are reviewed first at considerable length. Then, the role and limitation of science in tidal flat management in Korea are discussed. In brief, the present volume introduces the topics as following:

- Location and environment of the Korean tidal flats,
- Historical review in the use of the Korean tidal flats,
- Shihwa and Saemangeum cases as a tipping point in tidal flat management in Korea,
- Current status of the scientific effor for the Korean tidal flats,
- Integration of science and policy in designation and management of CWPAs in Korea.

2. Characteristics of the Korean tidal flats

The west and a portion of the south-west coasts of Korea are characterized by an extensive tidal flat system (Figure 1). The present coastal wetlands, which are composed largely of estuarine and tidal flats, were created during the post-glacial Holocene sea level transgression (Park, 1987). Macro-tide regime of up to 10 m and a very shallow bottom slope have created well developed

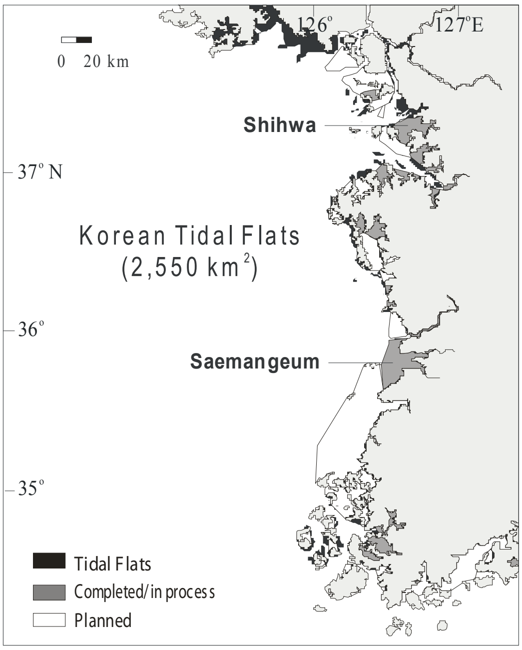

Figure 1: Map showing the Korean tidal flats developed along the west and south coasts of Korea, total area of the tidal flats is ca. 2,550 km², and about half of these areas are reclaimed and presently turned to land or lake.

tidal flats that extend 4-10 km perpendicularly from the crenulated ria-style shorelines. In this region, approximately 2,550 km2 of the seabed is exposed to the air during the lowest ebb tide (MOMAF, 2003). About 83 % of tidal flats are located in the west coast, amounting about 2,100 km2 while about 17 % (450 km2) relative to total areas of tidal flats are located in the south coast, in Korea.

A common feature of all Korean tidal flats is the extensive bare sand or mud flat, with a lack of oyster beds, salt marsh and mangrove forest which distinguishes them from other temperate and tropical wetlands. Lack of salt marsh is due to major embankments built near the shoreline during the early 20th century. Very fast dynamic tidal currents flood and drain on the tidal flat, engraving it with branching channels.

Korean tidal flats are characterized by high biodiversity and great biomass. Based on the national five-year monitoring program, during 1999-2004, 851 species were observed, including 164 diatom and 687 faunal species (MOMAF, 2005). The great biomass and productivity can be easily observed. For example, in a certain area of Hwaong tidal flat (reclaimed in 2002) as many as 500 individual razor clams (Sinonovacula constricta) could be found per unit square metre.

3. History in the use of the Korean tidal flats

Korean coastal wetlands have a long history of intensive human use through reclamation for agricultural and some industrial uses. Here, we describe the historical use of the Korean tidal flats along with 4 classfied periods (Table 1).

3.1 The 1st (1910s–50s) and 2nd (1960s–80s) Periods

The first period (1910s-50s) includes the Japanese occupation of Korea (1910-45), when the current pattern of systematic converting of wetlands into farmland started. During the period, the Japanese created rice fields in coastal wetlands as part of their attempt to increase rice production to support the Japanese army. The Joseon (Korea) Public Waters Reclamation Act, along with the attached Joseon Rice Yield Plan, was enacted in 1923 in order to politically support the above plan. The total acreage reclaimed for rice cultivation during the Japanese occupancy reached 564 km2 (Koh, 2001).

During the most active period of reclamation, between 1926 and 1934, very effective incentive and tax reduction policies contributed to the reclamation of 215 km2 of coastal wetlands. The next major period of wetlands conversion started in the 1960s at the start of modernization and industrialization in Korea. Another 550 km2 of wetlands was converted to agricultural and industrial lands between the 1960s and 1980s.

3.2 The 3rd period (1990s)

This period was characterized by large scale reclamation projects, ambitious engineering, and political propaganda in order to extend territorial land and secure food production. Reclamation has been strongly promoted through presidential elections, none of which supported environmental protection. Two of the most famous projects are the

Table 1: The four periods of wetlands use in the recent history of Korea.

Periods	Total size reclaimed (km²)	Purpose of reclamation	Reclamation approach
1910s - 1950s	564	Agriculture	Traditional technology in small-scale & near-shore
1960s - 1980s	550	Agriculture & Industry	
1990s	800	Industry & Agriculture	Advanced technology in large-scale
1999 - present	270		

Saemangeum and Shihwa reclamation projects. The Saemangeum reclamation encompassed 400 km2 of estuarine tidal flats with a 33 km-long dike. The Shihwa project, which began in the 1980s and completed construction of a 12.7 km-dike in 1994, reclaimed another 170 km2 of coastal wetlands. A total of ca. 800 km2 of wetlands were reclaimed during this period.

The average reclaimed area per project was about 1 km2 through the 1980s. However, the rate jumped up to 12 km2 between 1990 and 1994, and further to 32 km2 after 1995 (Koh, 2001). The remarkable increase was largely owing to the changes in embankment design adopted during this time. Due to technological limits, traditional reclamation projects built dikes to reclaim small, near-shore areas of the tidal flats. However, since the 1990s new technology has enabled reclamation of large sections of tidal and sub-tidal areas. However, in these huge modern embankments, the evidence of severe ecological degradation was expected to be obvious, especially when they encompassed estuarine wetlands (Sato and Koh, 2004).

Debates in the news media over the ecological damage caused by the two large reclamation projects have raised public awareness of the importance of wetlands. The repeated debates in the 1990s about the Shihwa and Saemangeum projects were particularly instrumental. Given the importance of the two projects as a tipping point of tidal flat policy in Korea, we briefly summarize the Shihwa and Saemangeum projects in the following sub-sections. More detailed information on these two projects can be found elsewhere (Cho, 2007).

3.2.1 Shihwa reclamation project

The Shihwa reclamation and dike construction project started in 1987 and finished in 1994. During the project, a new industrialized city (Ansan-si) was built without regulation bordering the bay. As a result, huge amounts of industrial wastes and sewage flowed into the bay, causing unexpected negative impacts on the coastal environment. The dike completion resulted in a highly polluted artificial lake that was originally intended to keep freshwater for agricultural use but ultimately it could not be used for the original purpose. In 1997, the gates in the dike were opened to allow water in and out in order to restore the degraded water quality of the freshwater lake. Unfortunately it failed to solve the problem. The Korean government finally gave up its freshwater storage policy de facto in 1998 and officially declared its abandonment of keeping freshwater in 2001. Since then, the original plan has been totally re-evaluated and reconstructed by the Shihwa District Policy Committee, which is made up of diverse stakeholders. Presently, the original purpose of Shihwa project (viz. agricultural use) has been changed into the tidal power project which is due to generate 254 KW upon completion in 2010.

During the dike construction, efforts by the government to compensate the coastal resource users were fraught with conflicts within the community regarding the distribution of compensation payments, and over losing their rights to utilize the coastal resources. Most of the Shihwa residents left the coast to seek employment in urban areas.

It is evident that the original Shihwa project totally failed, from which Korean society learned a valuable lesson by paying highly expensive social cost. Despite the bitter experience with the Shihwa project, it was followed by another similar case, namely the Saemangeum reclamation project, from which our Korean society suffered again.

3.2.2 Saemangeum reclamation project

The Saemangeum project was created by a presidential election commitment in the late 1980s. It started in 1991 with the 21-year project period to 2011 and total budget was estimated of 2.1 billion USD. After the failure of the Shihwa project, the Saemangeum project was the subject of great attention from the public in the mid 1990s. Heated debates raged in the following years over whether the project should continue or be stopped and Korean society faced a situation similar to Shihwa again.

In 1999, the Prime Minister ordered a stop to the dike construction and called on the joint survey committee for a feasibility study, including an environmental impact assessment. The committee, comprised of 9 governmental managers and 20 non-governmental scientists, was jointly recommended by the Korean government and NGOs. There was a severe dispute between committee members regarding methodology and feasibility study results. However, the Prime Minister decided to continue the project on condition that half was developed, and the rest considered later, depending on the pollution status of the artificial lake. Many scientists were against the governmental decision, arguing that it lacked a good feasibility study. Unfortunately, science itself did not seem to provide the tool to solve the social debate on the complicated environmental issue.

Over a period of two months in the spring of

2003, a long procession of people composed of clergymen, civic group members and environmentalists completed a 'three steps and one deep bow' pilgrimage of 300 km from Saemangeum to Seoul, protesting the Saemangeum project. This protest sparked fierce debates about wetlands reclamation (Korea Herald, May 30, 2003). Society's view about the Korean tidal flats shifted considerably, favoring conservation by virtue of this single, highly successful activity.

Eventually, the legal system was charged with resolving this long-running conflict. In July of 2003, the Administrative Court recommended to both the plaintiff (NGOs) and the defendant (pro-development) that a committee including diverse stakeholders would be established under the President or Congress to decide the scope and extent of development of the newly created land. Building the dike would be temporarily stopped until the committee decision made.

In December of 2004, a second judgment, by the High Court, overturned the first decision and favored the development. Finally, in March of 2006, the Supreme Court concluded its decision that there was no reason to stop the Saemangeum project. Immediately following the final judgment, the Korean government threw all its resources into the construction work and completed the dike on April 21, 2006. The result was that the Saemangeum tidal flat was erased from the Korean map forever.

3.3. The 4th Period (1999-present)

The public perception of tidal flats in Korea has changed from seeing them as bleak wasted lands that should be reclaimed, to seeing them as precious wetland systems worth preserving. This shift in opinion resulted in the Wetland Conservation Law (WCL) of 1999 and the designation of tidal flats by the government as protected areas began in 1999. This can be considered the 4th period in the history of use of the Korean tidal flats. While the first three periods focused on reclamation, the last period has seen nine sites designated as CWPAs, and among these, three are designated Ramsar sites. Even though a new reclamation project to harness tidal energy has been proposed in Ganghwa tidal flat, the contemporary period is still a turning point as Koreans have begun to realize the problems and lack of benefit associated with large-scale wetland developments. Most Koreans now seek a wise use strategy, and look to conserve the natural treasury of coastal wetlands for the next generation.

4. Science *versus* Policy: the Korean Experience

To assess the extent to which scientific data are incorporated into the policy-making process such as CWPAs designation, the literature surveys and review are performed as part of this study. We could find about 300 domestic and 100 international papers, with the topic of the Korean tidal flats, published in peer-reviewed journals for the last 30 years and major topics were found to be biology and geology. Among the most well studied topic in biology are ecology and taxonomy. Sedimentology was found to be the most prevalent study in geology. Remote sensing has been recently emerging as a hot issue in tidal flat geology as well. However, those scientific efforts seem to be limited to personal research among interested scientists and may not be appropriate for high-level policy-making processes.

Along with the legislation of WCL in 1999, the national survey on the Korean tidal flats has started to directly use the research outcomes in the policy-making process. The first phase of the national survey has been performed between 1999 and 2004 with the funding of 1.8 million EURO in total. The ongoing second phase of the national survey started in 2008 with a total budget of 3.6 million EURO by 2012. The first five-year survey aimed to accumulate basic monitoring data on social-ecological information of the entire Korean tidal flats. It could provide the inventory of coastal wetlands as divided by 544 unit areas, 69 larger units and 8 regions, respectively. Several grading systems are proposed to classify tidal flats based not only on physical environments but also ecological and social features. It was applied to scoring and grading eight intensely-studied areas for the stage prior to CWPAs designation. GIS mapping has also been performed to identify land use, habitat, benthos distribution and historical change of coastline, within those eight selected regions of tidal flats.

However, the survey results have failed to influence the decision-making process and management of tidal flats due to incomplete data collection and data features that are irrelevant to management purposes. Even though the survey could provide the grading system to prioritize tidal flats for the purpose of CWPAs designation, the consultation with stakeholders, rather than the best available scientific data, was the likely determining factor in the process of CWPAs designation at local level.

Meanwhile, it should be noted that Suncheon CWPA, designated in 2003, was recognized at the 2008 Ramsar Convention and the ecological benefit of Suncheon was highlighted. A successful meeting of the 2008 Ramsar Convention and the best practice of Suncheon CWPA brought public attention followed by systematic review for scoring and grading system for CWPA designation. Accordingly, the survey items included in the second-phase of national survey have been incorporated into the modified guidelines for CWPA designation, encouraging a science based policy-making process for CWPA designation in the coming years.

Given the short period of scientific tidal flat management in Korea, it may not be appropriate to compare the Korean case directly with the Wadden Sea practice in terms of the integration of science into tidal flat management. Since the three Wadden Sea States started the cooperation through the trilateral governmental conference in 1978, legal, social and policy basis have been deliberately formulated to achieve, as far as possible, a natural and sustainable ecosystem, where natural processes are well represented (CWSS, 1991). Over the years, the role of science in Wadden Sea policy has gradually shifted from the supply of fundamental knowledge about the human and natural system towards policy, management and monitoring (Van der Windet, 1992).

As we have shown, the conservation of the Korean tidal flats is only just beginning. It is encouraging that government and general public are now eager to focus on the conservation side rather than development in Korea. WCL provides a strong legal support to this trend. Currently, the second phase of the national survey is reaching a point where aims will shift towards the integration of science and policy. Based on the accumulated knowledge and lessons from the first five-year survey, it should be essential to have consistent data collection methods by virtue of relevant guidelines. Besides, international examples reveal the importance of effective science in crossing the boundaries between communities of experts and decision makers, in terms of effective communication, translation and mediation (Cash et al., 2003). It should be stressed that science should be used to effectively manage the boundary between them in the follow-up national survey.

Overall, we found that the outcomes from the tidal flat science work in Korea have been partly used to identify CWPA candidates; stakeholder consultation was likely to have bneen the more important factor in final designation of CWPA at the time. It is evident that there are some gaps between science and policy in the management of the Korean tidal flats, in general. The lessons and experiences of forerunners, the Wadden Sea Symposia, provide valuable insights. Therefore, we have a delightful hope that science will evolve towards playing an essential role in tidal flat conservation and management in Korea in future.

5. Conclusions

- Society's view about the Korean tidal flats shifted considerably towards favoring conservation by virtue of the two environmental issues of Shihwa and Saemangeum projects.
- The role of science in tidal flat conservation in Korea is limited due to its short history and lack of quality, but science still has an essential part to play in identifying CWPA candidates.
- Improvements are necessary not only to encourage the quality of scientific effort but also to enhance communication between information producers and users.

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Marine and coastal management in West Africa: partnerships, progress, and prospects

Paul Siegel, WWF WAMER, P.O. Box 22928, Dakar, Senegal, psiegel@wwfsenegal.org

1. Background and Context

The Western African Marine Ecoregion (WAMER) extends along nearly 3,500 km of coastline and covers some 1.4 million square kilometers of the east-central Atlantic. It is bounded on the north by the cold water Canary Current which flows westwards across the Atlantic from Morocco/ Mauritania and on the south by the warm water Guinea Current which flows eastwards along the equator through the tropical Atlantic, reaching the African continent near Sierra Leone and following the coast westwards. It is one of the most biologically diverse and productive marine areas in the world, with over a thousand species of fish, 20 species of cetaceans, 5 species of marine turtles, and over 600 species of birds, many of which (like the Kentish plover in Figure 1) migrate annually between Africa and Europe.

Seven countries are included in the ecoregion: Mauritania, Senegal, The Gambia, Cape Verde, Guinea Bissau, Guinea and Sierra Leone with a combined population of over 32 million - most of which lives on the coast. Fishing plays a major economic and social role. In Mauritania, for example, which produces nearly 700,000 tons of fisheries products annually, fisheries access agreements (in particular with the EU) provide 50% of the country's foreign exchange. In Senegal, a country of over 12 million people, more than 600,000 jobs are linked to the sector.

Meanwhile, several different foreign fishing fleets (primarily from the EU, Eastern Europe, and Asia) ply the waters - contributing much needed foreign currency to national coffers but also adding to the unsustainable pressures on the limited amount of fish (Figure 2). Over the past 50 years the impact of over-fishing has been drastic. Where once, fishers could easily catch a day's food in minutes or hours, local fishers are now forced to spend days at sea - and even then they are not guaranteed a good catch.

Figure 1: Kentish plover (*Charadrius alexandrinus*), after Smit & Piersma 1998 (in www.jncc.gov.uk/PDF/ pub07_waterbirds_part1_ flywayconcept.pdf).

One of the unforeseen consequences of this progressive decline has been a dramatic increase in illegal immigration from West Africa to Europe as fishers risk the perilous sea crossings in search of employment.

Adding to the already complex situation is the growth of both the tourism and hydrocarbon industries. Both have the potential to significantly contribute to local and national economies but each carries serious risks: Hydrocarbons, because it is non-renewable and is often the source of environmental pollution and social destabilization and tourism because it is often accompanied by

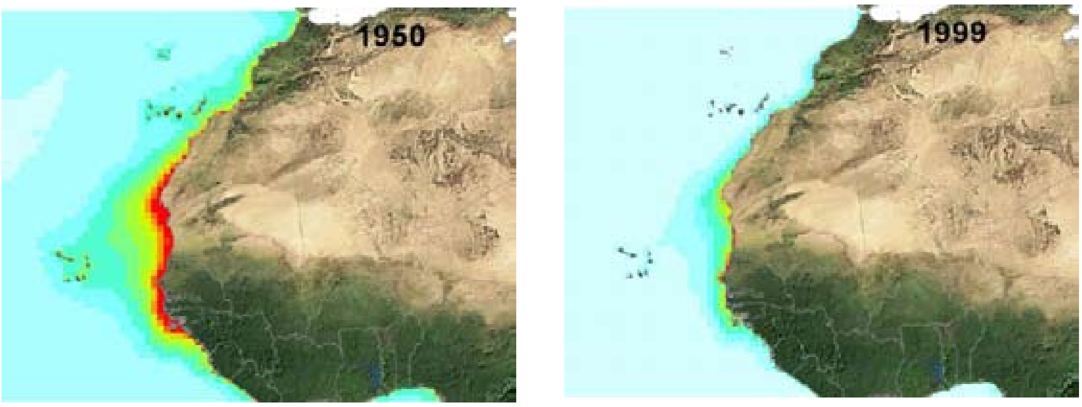

Figure 2: Fish population density (excluding small pelagics) from Dr. Daniel Pauly, University of British Columbia (red=higher, blue=lower).

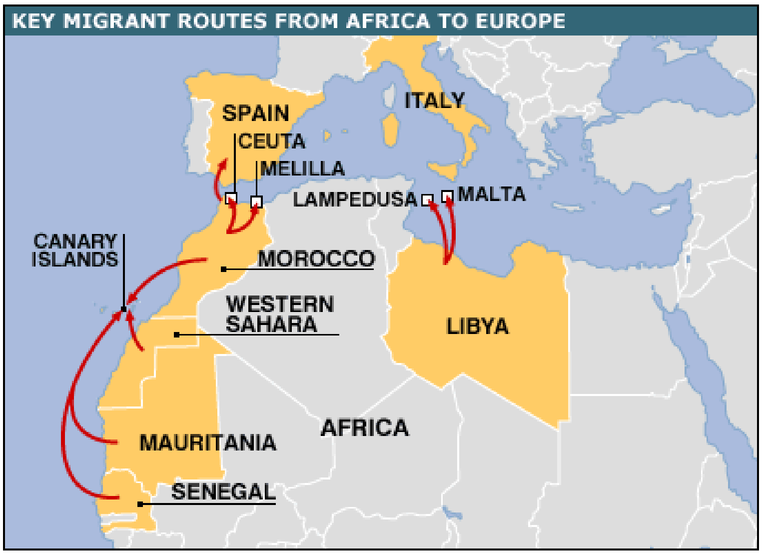

Figure 3: Key migrant routs from Africa to Europe ttp://newsimg.bbc.co.uk/media/images/42029000/gif/_42029904_africa_migrants2_map416.gif

the destruction of coastal and marine habitats and social disenfranchisement. Recent studies by Woodside Petroleum, for example, have demonstrated that an accident at the Mauritanian oil field at Chinguetti, could have serious consequences in the most important northern Senegalese fishing grounds as far as several hundreds kilometers away.

In short, the Wadden Sea and WAMER are linked ecologically, socially and economically, opening the door to expanding bilateral links to help protect nature and the millions of people who both appreciate and depend upon it for their very survival. The purpose of this paper is to present strategic options to form the foundations of this partnership and to provide examples from the West African experience.

2. Strategies for Sustainable Conservation

Four key strategies provide the foundation for WWF's marine and coastal work in West Africa. The first is to take a holistic view - treating conservation challenges from an "asset management" perspective and helping the resources owners and managers to achieve a dynamic balance between consumption and investment. Often, different agencies are charged with the consumption (fishing, tourism, etc.) and investment (protected areas, conservation measures, etc.) sides of the equation and non-governmental organizations like WWF can play a key role as "honest broker" to bring the different sides to the table to find mutually acceptable management models - like blending improved fishing techniques with the establishment of marine protected areas to protect key reproduction or nursery sites.

The second strategy is to ensure that resource users and managers are involved with all aspects of conservation programming, from the initial articulation of key threats and challenges to the implementation and monitoring of project effectiveness. In the long run, the responsibility for managing natural resources rests on the shoulders of nationals of the owner/producer countries. Any attempt to establish management

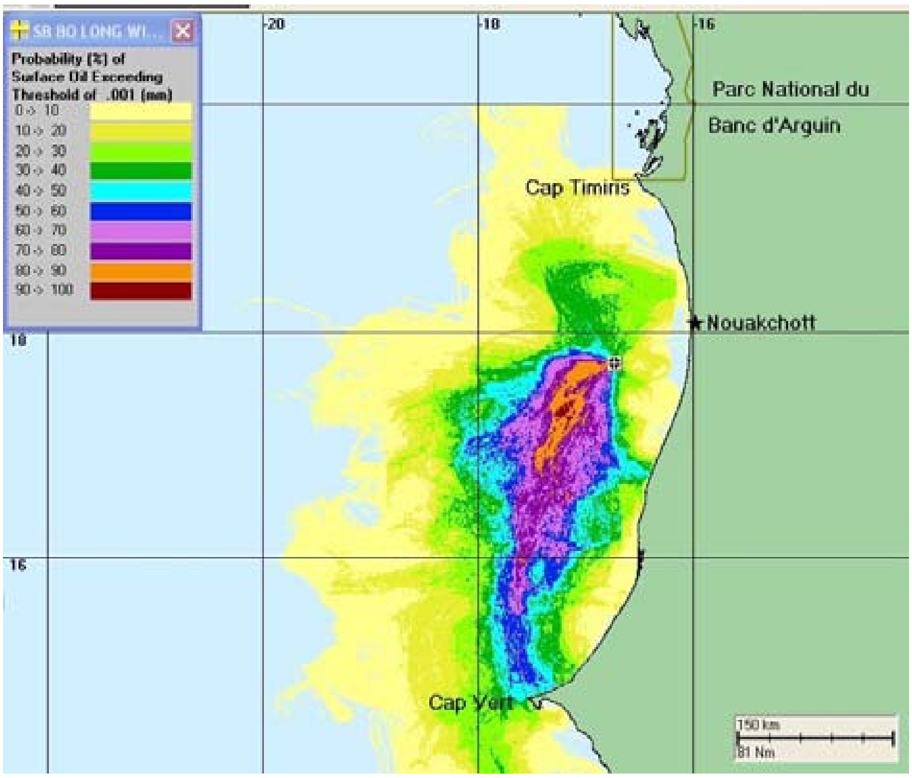

Figure 4: The Chiguetti site lies 80 kms SSW of Nouakchott, the Mauritanian Capital. Source: Woodside Petroleum, Environmental Impact Report, Chinguetti, Mauritania, 2003.

regimes without the full participation and guidance of indigenous institutions will inevitably run into problems once external funding stops. On the other hand, developing natural resource management programmes around the issues most important to local governments and communities, and working with local stakeholders to develop solutions that are socially, technically, economically and politically appropriate, goes a long way to ensuring good focus, promoting buy-in, and post-project sustainability.

Strengthening the capacity of local players: NGOs, government technical departments, civil society institutions like the media and professional associations – is another key element to setting the stage for sustainability. In the long run, these are the people and institutions which will eventually be called upon to manage countries' resources. However, capacity building only helps fill management gaps if those gaps are the result of an insufficiency of skills. Capacity building only builds the capacity to achieve it doesn't guarantee it. Capacity represents a potential, like putting extra water behind a dam. Without a mechanism to convert the potential power of the water, it remains untapped.

Ensuring that fishers have the requisite skills to successfully manage their local stocks will not get the job done if laws do not empower locals to make management decisions. In the case of Senegal, for example, until quite recently, fisheries management was centralized so communities were prevented from implementing management regimes even when they knew that important fish nursery zones were being overfished. On the other hand, the establishment of protected areas was decentralized – which created an opportunity that communities like Abéné, Bamboung, Cayar, Joal-Fadiouth and St. Louis seized to protect key spawning and maturation areas through the establishment of delimited and zoned marine protected areas

However, even with the best skills and most conducive legislation, balancing the natural budget is impossible if motivation is lacking. Sometimes people lack the necessary perspective to understand the interwoven nature of natural resource management and "development"; sometimes decisive actions (law development and/or implementation, budget allocations, etc.) are impeded by inadequate understanding of issues and options. Sometimes environmental concerns seem less important and/or pressing than economic and social ones when in fact they are simply two sides of the same coin. Non-governmental organizations can help fill the information gap through direct and targeted awareness campaigns and also through partnering with local advocacy groups and the media. In Guinea and Senegal, for example, WWF works closely with environmental journalists' associations to provide training and operational support. We also work closely with professional fishers' associations in all countries of the ecoregion to help them more effectively express their perspective and enter into meaningful dialogue with governmental and private sector operators.

Successful management regimes for multiple use areas depend on the active and coordinated participation of government, non-governmental organizations, and private sector actors. However, in many countries, these groups do not have a history of working together and organizations like WWF play an important role of catalyzing relations between them. In the long run, they are the ones ultimately responsible for ensuring environmental health and productivity.

Since many of the environmental issues facing individual countries of the ecoregion transcend national boundaries, regional efforts must be coordinated. In West Africa, four international NGO (WWF, IUCN, Wetlands International, FIBA) in conjunction with the Sub-Regional Fisheries Commission (a regional ministerial-level intergovernmental body)) established a coalition to play this role. The PRCM (Regional Programme for Coastal and Marine Conservation in West Africa (http:www.prcmarine.org) was launched in 2004 and provides a platform for all the ecoregion's players to reach consensus on marine resource management priorities and tools, coordinate training and skills enrichment, establish joint communications and monitoring programmes, and liaise with interested parties from within and outside the area. Currently, PRCM includes over 60 governmental and non-governmental organizations. Each participating party brings its own unique experiences, perspectives and capabilities to the coalition: Governments, for example, are uniquely competent with respect to the development and implementation of legal instruments. Research institutes can provide indispensable scientific analyses concerning, for example, the abundance and distribution of key species in their different life stages. National NGOs provide local knowledge and critical links to grass-roots users, while international NGOs bring their nonpartisan technical, fundraising and advocacy skills. Together, they focus their individual institutional strengths on achieving mutually important goals like establishing protected areas, promoting sustainable fishing, conserving endangered species and advancing natural resource governance.

3. WAMER and the Wadden Sea

Individuals and institutions of both the Wadden Sea and WAMER are focused on the same long-term objective: Conserving the ecological health and economic productivity of fragile environments. Strengthening ties between the two has the potential to facilitate mutual learning, provide greater leverage for the promotion common interests, and improve the coordinated management of shared species. Turning this potential into reality hinges on building bridges between the regions' governments, natural resource managers, scientists, and civil society organizations, built on shared interests.

At the governmental level, for example, the Wadden Sea counties' experiences in advancing intergovernmental cooperation and regional management of the shared ecosystem can inspire similar reflection among West African states, while experiences in West Africa with decentralized integrated coastal management could be valuable to northern States.

Better coordination between the two regions' natural resource managers would improve mutual understanding, promote the exchange lessons learned, provide a forum for discussion and resolution of issues of common interest, and improved the management of shared species.

Scientists too would benefit from stronger ties as a way to improve our understanding of the biology and ecology of our shared natural heritage and develop tools to monitor management effectiveness, objectively assess the impact of conservation actions on target species (including humans), and actively promote the best possible training for a new generation of professionals.

The responsibility for ensuring the sustainable management of our natural treasures lies ultimately with a country's people. Strengthening links between the Wadden Sea and West Africa would invigorate civil society and private sector organizations from both North and South. By sharing information, concerned NGOs, businesses, and local user groups can become better informed and take a more active role in the governance of these unique ecosystems which so enrich lives of millions and represent an incomparable inheritance for generations to come.

The Guiding Principle for the Wadden Sea: Advantages of a dynamic approach in a changing world

Hans-Ulrich Rösner, WWF Germany, Hafenstr. 3, D-25813 Husum, roesner@wwf.de

Abstract

The management for the Wadden Sea has been successful in preventing a further deterioration of the overall condition of its nature during the last 20 years. This positive statement is true only if pros and cons are balanced, i.e. there are also issues where there have been deteriorations during the last decades. It must also be kept in mind that nature was already badly affected before.

The Guiding Principle for the Wadden Sea favours natural processes whenever possible. It is among the major achievements of the three countries for the protection of the area, providing an overall umbrella against which management decisions can and should be measured. The Guiding Principle is also fit for the future, in particular as the use of natural processes may become increasingly important when active management options are tested which allow the Wadden Sea to adapt to an accelerated sea level rise.

Recommendations for future scientific work focus on how to apply the Guiding Principle in practice, how to adapt management to the challenges arising from invasive alien species, and how to adapt management to the challenges arising from sea level rise.

1. Introduction

This paper is about the present and future management of the Wadden Sea as a worldwide unique and protected nature area in general terms. The goal is to discuss whether the Guiding Principle for Wadden Sea protection from 1991 is fit for the future.

Therefore, I briefly describe the present management of the Wadden Sea, the advantages and disadvantages of the Guiding Principle as the overall guideline of this management, and whether it seems realistic that the management can be adapted to tackle future challenges. Finally, I give three recommendations. They aim to reflect those issues which presently deserve the highest attention in the Wadden Sea's scientific community.

This paper is focussing mainly on the protected areas of the Wadden Sea, i.e. the area outside the main dike line, including the more natural parts of the islands.

2. The present management of the Wadden Sea, its successes, and some predictions

The Wadden Sea and its management regime evolved over quite some time. Safeguarding of some seabird colonies began about 100 years ago. However, it was not until roughly 50 years ago that larger areas of the Wadden Sea became protected. The "Trilateral Cooperation" of the three Wadden Sea countries is about 30 years old, with the first "Joint Declaration on the Protection of the Wadden Sea" being decided upon on December 9th, 1982 by The Netherlands, Germany and Denmark. In parallel to this, the national Wadden Sea policies developed. In Germany three National Parks were designated from 1985 to 1990, with a total size of about 7,300 km^2 in 2009, covering almost the entire German Wadden Sea. The Dutch and Danish parts of the Wadden Sea also became protected, with Denmark deciding in 2008 that its Wadden Sea should also become a National Park soon. And at the time of writing this manuscript, it is just weeks until a decision by the UNESCO World Heritage Committee is expected on whether the Dutch-German part of the Wadden Sea will become a world heritage area (CWSS 2008).

All this sounds easy, but it was not. A great number of people worked very hard for the Wadden Sea and its protection for the past 100 years: local and non-local people, scientists and non-scientists, governmental and non-governmental organisations, professionals and amateurs. As of today, they form a kind of "Wadden Sea Network", finding expression e.g. in the regular trilateral governmental talks and decisions, nature organisations, visitor centres on almost every island and at many mainland sites, a trilateral Wadden Sea Secretariat and local administrations working for the protected areas. There are also a stakeholder forum (the "Wadden Sea Forum"), municipal organisations, advisory boards, and a trilateral environmental monitoring programme. And, not to forget, more than 200 scientists who show up at events called the "International Scientific Wadden Sea Symposium"!

This work also resulted in a set of regulations and a management framework having been developed specifically for the Wadden Sea, a prerequisite in setting the scene for successful conservation. Of particular importance is the national nature legislation on the Wadden Sea in all three countries (e.g. the "Planologische Kernbeslissing" in The Netherlands or the National Park laws in Germany). This, however, is bound together by a kind of „soft law" being decided jointly upon by the three countries in the Trilateral Cooperation. Trilaterally there is a clear overall objective – the "Guiding Principle" (see 3.) – and a number of targets for the different habitats and some species groups (TWC 1991, TWC 1997). The national and the trilateral levels of policy making has always influenced each other and many issues have been solved jointly and in a compatible way. However, part of the management always remained country specific.

Above these national and trilateral regulations reside a number of European Directives relevant for the management of the Wadden Sea, mainly the Birds and the Habitats Directives (both together as Natura 2000), and more recently the Water Framework Directive and the Marine Strategy Framework Directive. They set important conservation standards to be fulfilled even if and when they are sometimes considered uncomfortable from a local or national point of view. However, as positive as these European standards are, the implementation of these directives is quite a complex issue, because they differ in the area concerned, in their goals and in the time schedule within which the countries have to fulfil their duties.

Overall, the management of the Wadden Sea as it has developed certainly is one expression of "Integrated Coastal Zone Management" – though usually not named as such and with much potential for improvement.

All what has been mentioned up to this point was about people: their goals, their science, their organisations and their regulatory frameworks. Nothing has been said so far about the quality and the condition of the Wadden Sea's nature itself, on which all this is focussing. The best available overview on this can be found in the "Quality Status Reports" (QSR) for the Wadden Sea, the most recent one at the time of writing by Essink et al. (2005). The conclusion of the synthesis chapter in this report binds everything together: "The present Wadden Sea is a particular habitat problem area and still deficient in a number of charismatic species which once lived in this region. This is mainly the result of various pressures exerted by human activities. Relevant issues for the future are also an increasing impact of introduced species, the consequences of sea level rise and an assumed trend towards sandier sediments. Precaution requires the further reduction of the release of technogenic toxic substances and the prevention of the release of new ones. The need for balancing the reduction of nutrient enrichment deserves to be critically assessed. Future management of the natural values of the European Wadden Sea should be better tuned to the apparent differences between sub-areas as well as taking into account the cross-boundary relationship between this system and the influences from large river catchment and offshore areas." (Reise et al., 2005).

This describes the situation very well. However, the QSR does not give a clear signal whether the condition of nature – as problematic as it still is – has improved or deteriorated since the time when bigger thinking began to have consequences for Wadden Sea protection, i.e. over the last 20 years. Only by answering this question we can assess how successful all the conservation efforts may have been. However, it may be quite difficult to get a scientifically sound answer on this. There would be so much artificial weighing of so many indicators involved, that different people doing this analysis might well come up with different answers. Looking at many of the pros and cons about what has improved and what has deteriorated (see also WWF & Schutzstation Wattenmeer 2005, WWF 2006), my hypothesis is that nature condition in the Wadden Sea has been reasonably stable during the last 20 years. Again, the terms "improved", "deteriorated" and "stable" as I understand them here are describing the condition of nature as such – not in terms of the quality of laws, management plans and other regulations.

Is this a success then? So many people's work, and then the condition of nature has only remained stable? Certainly Wadden Sea protection should and could have been more successful. But, compared to the alternative of no or fewer protection efforts, and compared to so many other places in the world, Wadden Sea protection has been quite successful. This certainly does not mean that there is no need for further and improved action, as I will show later. It means that all the efforts of so many people for so many years have not been for nothing and also not just for a little bit, but that they really have achieved a lot and that their work was well invested!

Having described the present situation and the trend up to now, I would like to risk some predictions for the future. Certainly without being complete, Table 1 lists the major issues for conservation and management, both as they can be considered now and with an outlook to the future. The latter is purely based on personal assumptions and what can be expected if one is more optimistic than pessimistic and if the Wadden Sea network is doing a good job. The result looks rather good for the Wadden Sea, with one exception: Sea level rise and other effects of climate change may become so dramatic that their effects cannot be fully compensated.

Table 1: Major conservation and management issues in the Wadden Sea (not complete), expectations from an optimistic viewpoint and necessary actions, and chances for improvement (+), stability (±), or deterioration (-) in the long term.

Present situation of conservation and management	Expectations and necessary actions	Chance for improvement
So many people work for the Wadden Sea, a great **network**. However, resources are still missing in many places and for many issues.	Improve quantitiy and efficiency on all levels (governmental and non-governmental). Stable Wadden Sea funds required in the entire region. Improve cross border cooperation on specific issues. Strengthen cooperation of visitor centres as well as cross border education.	+
A reasonable **regulatory framework** and a clear overall objective do exist. Some rules have too many detrimental exceptions and some could be made less complex.	The negative effects on the ecosystem caused by inappropriate regulations are not so serious that this could not be repaired, possibly with an update of the Wadden Sea Plan as one component, including a better integration of the EU directives. However, making things less complex must not mean less protection.	+
The whole Wadden Sea is a **protected area**. Recently DK decided upon a National Park and there is a good chance that the NL-DE-Wadden Sea will become a World Heritage Site soon.	Both National Parks and the World Heritage Site should become the joint tools for management and marketing in the entire Wadden Sea. All this is „insurance" that society will take the protection of the Wadden Sea more seriously in the future.	+
Parts of the Wadden Sea are heavily influenced by **industrial activities**, with even plans for increase (e.g. oil and gas drilling, coal power plants, carbon storage, harbour developments, deepening of estuaries, cable routes).	Industrial pressure could grow to an extent that the Wadden Sea severely deteriorates. This is a risk that is not dealt with appropriately yet. Strong action is needed to stop certain activities, and to truly compensate for the others.	±
Fishery is not yet managed well enough, both within the Wadden Sea and in the North Sea (with the latter also affecting fish populations in the Wadden Sea).	Improvement is possible and probable by better management, and by complying with the protection goals. This should result in a fishery still safeguarding local jobs, but leaving large parts of the protected area untouched.	+
Invasive alien species are found everywhere, some already with severe effects on the ecosystem. Management has largely ignored the issue so far.	The effects on nature will increase, and more species will invade, which in most cases is irreversible. The Wadden Sea could globalize too much while the natural biodiversity becomes less visible. New regulations must stop further introductions through both with water and aquaculture. Furthermore it may be possible to find measures to reduce effects of already introduced species, particularly in some terrestrial habitats.	±
Tourism – including its infrastructure – has a severe influence on nature. However, the zoning system, visitor centres, guided tours and an increasing number of stakeholders behaving responsibly help a lot in mitigating the impacts. Positive also is an increasing cooperation between tourism and conservation.	Rising temperatures in the South could increase tourism in the Wadden Sea to unsustainable levels. Also new fashion sports may bring problems. However, an overlap of interests between tourism and conservation about keeping the Wadden Sea as a beautiful landscape makes it probable that problems can be coped with in the future.	±
Coastal defence – in the past the largest impact on the ecosystem – and conservation are still not integrated enough. However, there are the first examples where conflicts of the past have been replaced by cooperation.	With a view on the effects of an accelerated sea level rise, an alliance between coastal defence and conservation is required, with coastal engineers aiming for both safety for the people and nature protection. This should be possible to achieve.	+
As of today the measurable effects of **climate change and acceleration in sea level rise** are still rather minor.	Sea level rise and other effects of climate change will be so dramatic that it may not be possible to fully compensate. There is hope that we can adapt to an extent, which would still allow the Wadden Sea to continue to exist and remain beautiful. However, to achieve this much needs to be done.	-
People love the Wadden Sea - both locals and tourists.	It can be assumed that people continue to love the Wadden Sea. This is among the major reasons why it is probable that the futhre challenges may be coped with!	+

3. The Guiding Principle as the management umbrella for the Wadden Sea

Three industrialized countries cooperating for a large and unique nature region – obviously there must be a guideline as an umbrella for the management. Such a guideline should fit the overall picture we would like to see in the landscape and safeguard a rich variety of all typical species and habitats. Therefore, at the Trilateral Wadden Sea Conference in Esbjerg in 1991 the three governments decided (TWC 1991): „*The guiding principle of the trilateral Wadden Sea policy is to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way.*"

This decision made clear what the focus of conservation should be in the future: Nature should simply take its course to the extent possible. By this the Guiding Principle provided rather objective criteria for management. Therefore, there is no need to decide on more or less artificial goals such as specific population sizes for certain species or how to develop favourable habitats just because we like them more than others. Also, a clear goal like this is easy to communicate and to understand for everybody. The Guiding Principle also helps to save money: The alternative – a much more active management – usually costs more.

The underlying assumption for the Guiding Principle as the right way to go was the following: the Wadden Sea is large enough that if we leave it rather alone and restore it where necessary it is very likely that all naturally occurring species and habitats will occur.

The Guiding Principle's message is limited by the term "as far as possible". A typical example for this limitation is when coastal defence measures – which often restrict natural processes considerably – are needed for reasons of public safety. Also, with quite a fixed border between the land and the Wadden Sea and also at the mouths of many small and large estuaries, it is obvious that important components of natural processes occur on a very limited basis only. However, the term "as far as possible" may also apply to certain exceptions concerning conservation purposes. There seems to be three cases where a more active management would comply with the Guiding Principle:

1. If the underlying assumption that all habitats and species can be conserved or restored under the Guiding Principle was violated and if the active management required for compensation would occur on a local scale only. This could be the case e.g. with endangered species requiring special protection measures according to the Natura 2000 Directives. An example could be the help for Sandwich tern (*Sterna sandvicensis*), which – because too few islands are left undisturbed as breeding sites – are breeding at so few sites that some species management might be justified.
2. If there is a human impact anyway, then those techniques or measures should be used which support best the natural dynamics. This would then by definition become the „Best Environmental Practise" for the Wadden Sea.
3. If large scale human impacts affect the natural processes to an extent relevant for the overall natural patterns, then the impact of a compensatory active management lowering the overall impact could be acceptable. Possible examples could be related to the fixation of the border to the land or the estuaries, to invasive alien species which were introduced by man, or to the consequences of the accelerated sea level rise.

The national policies in all Wadden Sea countries seem to have incorporated the content of the trilateral Guiding Principle. Examples are the National Parks in Germany: In their aims they are close to following the international definition of such high level nature protection areas, i.e. large undisturbed landscapes where natural processes are allowed to proceed.

Is the Guiding Principle realistic?

However, there are also doubts whether the Guiding Principle provides the right management umbrella:

There are so many impacts such as extractive uses, fisheries, tourism, pollutants, nutrients, alien species, shipping, fixed coastline, devastated estuaries – to mention just a few. And, above all, there is climate change with an accelerated sea level rise, which could have consequences up to destruction of the Wadden Sea. Arguing pessimistically, this seems to make undisturbed natural processes unlikely. Arguing optimistically, just go out in the Wadden Sea and you will see almost undisturbed natural processes in action – far from being perfect, but probably the best we have in Western Europe. Also, the Guiding Principle should be understood both as guideline and a goal, not as a description of the present situation. We certainly have to focus also on how nature could be restored in some areas where natural processes do not prevail at present.

Does the Guiding Principle comply with European rules and regulations?

The Natura 2000 Directives are setting clear goals for species and habitats, but not so obviously for natural processes and beautiful landscapes[1]. However, as argued above, priority for natural processes in a very large and rather natural area like the Wadden Sea will usually provide room for all species and habitats to be protected there. In the details of management this can be quite complicated, particularly as several directives apply to the same area and need to be handled in an integrative manner. The idea of a more regional approach provided by a Wadden Sea Management Plan and accepted by the EU could be helpful both for the right decisions in nature conservation and for user interests. However, finding the right balance for this is difficult, as a run for the "lowest protection level" may not be allowed and the conservation standards set by the EU directives must be kept. A solution for a more regional approach might in fact be provided by the Guiding Principle: With the priority of natural dynamics it sets an objective standard which may be violated only in defined cases such as those mentioned above.

Is the Guiding Principle still relevant considering the challenges arising from climate change?

It could be argued that a focus on natural processes in the future seems luxurious when it comes to survival for both people and ecosystems with a changing climate and all its side effects, among them an accelerated sea level rise. However, natural and large ecosystems will in many cases cope best – and with fewest management costs – also with climate change. This might be particularly true in the Wadden Sea: Even the adaptation to the coming sea level might work best if it is based on measures using natural processes to the largest possible extent, e.g. sand nourishments at the sandy islands. Beside this, it is also quite probable that the generations to come also would like to see nature at its most beautiful. We should keep this option for them.

4. Recommendations

This is not a list of all recommendations necessary for the protection of the Wadden Sea. It is rather an attempt to highlight the issues which should be much more in the focus of scientific research if we want to solve the problems that are arising at present or will arise in the foreseeable future.

Recommendation 1: There is a need for more research on how to apply the Guiding Principle

Some very important work areas arise from the Guiding Principle as the management umbrella for the Wadden Sea:

1. There is a lack of research leading to a deeper understanding of natural resilience and of the processes keeping the ecosystem running (and beautiful...).
2. There is a lack of research about the balance between active management on a local scale and when and how it may be required, and the general priority for natural processes.
3. There is a lack of research about how it can be achieved that human uses/impacts exert the lowest possible influence on the natural processes.
4. There is a lack of research supporting decisions on when active management on a larger scale might be required/justified, mainly with respect to compensation of large anthropogenic impacts.

Recommendation 2: There is a need for more research on how to adapt management to the challenges arising from invasive alien species

It is difficult in these days to visit the Wadden Sea without immediately being confronted with alien species, the most prominent example being the Pacific oyster. It is becoming clearer and clearer that the problems arising from this have been strongly underestimated in the past. Today the conflict with conservation goals is obvious, as the species composition is about to move in a direction similar to that occurring elsewhere in the world and thus to become less unique. Invasive alien species also bring risks for economics, and the EU has taken up the issue quite high on the agenda[2].

In principle there are two management measures to be used: Avoiding further import (e.g. with ballast water or for aquaculture) and eliminating invasive alien species at a time when this is still possible. For the Wadden Sea there is a need to study also the second option, e.g. whether it may be possible to eliminate alien plant species from certain islands and thus give natural dune vegetation a chance.

1 But see also EU parliament resolution on Wilderness in Europe from February 2009 (www.europarl.europa.eu/oeil/FindByProcnum.do?lang=en&procnum=INI/2008/2210), which support Europe's last wilderness areas and calls both for coherence and for a special role and extra protection for wilderness zones inside Natura 2000 areas.

2 See http://ec.europa.eu/environment/nature/invasivealien/index_en.htm

Recommendation 3: There is a need for more research on how to adapt management to the challenges arising from sea level rise

Tidal flats, saltmarshes and islands are threatened by erosion in a number of tidal basins where the natural speed of sedimentation cannot cope with the speed of sea level rise (CPSL 2001). If we do not want to lose the Wadden Sea due to a man-made accelerated sea level rise, we need to support an adaptation to a much higher sea level. Unlike the decisions required for climate protection, there might still be some time remaining for decisions on this adaptation – but early preparation may be cheaper and more successful.

The need for adaptation should already be reflected in the next Wadden Sea Plan targets: The size of saltmarshes, the tidal area, dunes and beaches should remain on the level of today, which should be defined as a reference level. It is important to set such an ambitious target, knowing that it will not be easy to achieve under the conditions of an accelerated sea level rise. It actually may imply active management of both the nature and of human behaviour to compensate for this enormous human impact:

- Using natural dynamics as much as possible to encourage the „Growing with the Sea" (e.g. WWF 1996, Reise 2006).
- Import of sand from the North Sea into the system (e.g. Reise & Lackschewitz 2003, Reise 2007).
- Softening the border between land and sea (e.g. allowing sedimentation in low lying marshland, in some places – particularly in estuaries – possibly moving the border inland).
- Changing the way we build houses in unsafe areas, and also the places where houses are built.

There is a lot of research required concerning these issues, including large experiments and pilot projects on new and nature friendly methods. Actually, research will not be enough. It will be just as important that the objectives for coastal defence become broader: Both the safety of people and their property, and the care for the Wadden Sea nature and landscape must become the joint focus, resulting in an alliance between coastal engineering and nature conservation.

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Ecosystem, Species Trends and Assessment

Decreasing eutrophication of the Wadden Sea: how low should we go?

J.E.E. van Beusekom
Wadden Sea Station Sylt, Hafenstrasse 43, D-25992 List/Sylt, Germany
justus.van.beusekom@awi.de

1. Introduction

One of the main factors influencing the quality of the Wadden Sea is eutrophication. First indications of an increased turnover of organic matter were given by de Jonge and Postma (1974) who observed tripling organic phosphorus concentrations between the early 1950's and 1971-1972 in the Western Dutch Wadden Sea. First indications of an increased primary production were observed by Cadée (1986) reporting a doubling between the early 1970s and the mid-1980s. Eutrophication is one of the factors linked to the decline of seagrass (van Katwijk *et al.*, 1997; Reise *et al.*, 2008), the increase in green macroalgae (Reise and Siebert, 1994) and increased blooms of *Phaeocystis* (Lancelot *et al.*, 1987).

Evidence now accumulates that the maximum eutrophication was reached during the mid 1980s and a decreasing eutrophication levels has been observed since. Riverine nutrient loads into the Wadden Sea area have decreased (van Beusekom *et al.*, 2005). Philippart *et al.* (2007) observed decreasing concentrations of Phosphorus and Nitrogen in the Marsdiep area. Winter nitrate concentrations in the northern Wadden Sea (List Tidal Basin) show a decreasing trend correlated to riverine Total Nitrogen input by Weser and Elbe (van Beusekom *et al.*, 2008).The decreased nutrient concentrations influenced the phytoplankton productivity and species composition. Cadée *et al.*, (2002) observed a decrease in primary production in the Dutch Wadden Sea since about 1995. In the List tidal basin, van Beusekom *et al.* (2008) observed a decrease in summer phytoplankton biomass (as chlorophyll) significantly correlated with riverine Total Nitrogen Input via Weser and Elbe. Philippart *et al.* (2007) found a significant relation between limiting nutrients (P and Si) and phytoplankton community structure. The latter authors give evidence that the reduced eutrophication had in impact on the higher trophic levels (macrobenthos, birds). The decreasing eutrophication may have played a role in the current sea grass recovery (Reise and Kohlus, 2008) and in decreasing green macroalgae coverage in the northern Wadden Sea (van Beusekom *et al.*, 2009).

The Quality Status Report 2009 (van Beusekom *et al.*, 2009) basically confirms earlier results presented in the Quality Status Report 2004 of a Wadden Sea-wide reduction of the eutrophication status. In short, riverine Total Nitrogen and Total Phosphorus loads further decrease (Fig. 1) with an annual rate of 2-3% per year (discharge normalized loads). Most of the time series (Western Dutch Wadden Sea, Ems-Dollard, Norderney, Sylt, Grådyb) show a significant decrease in summer Chlorophyll (mean of the monthly means for May-September). Autumn levels of NH_4 +NO_2 (van Beusekom, 2001)

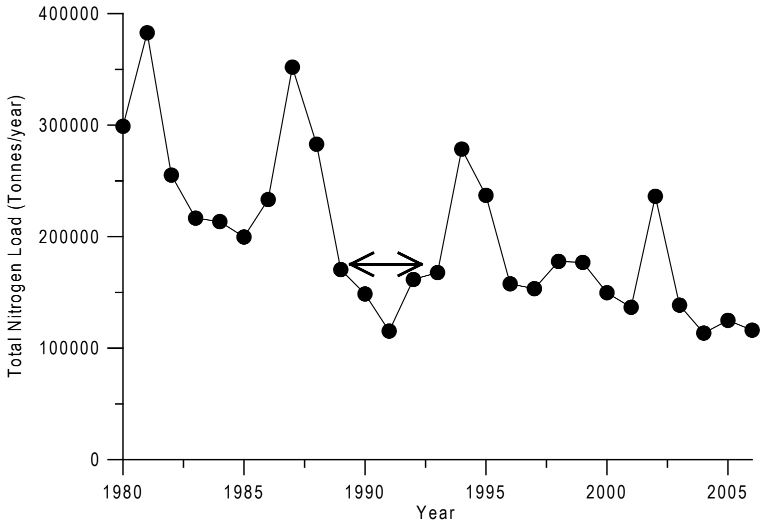

Figure 1: Annual Total Nitrogen load of the rivers Elbe and Weser. The arrow indicates the period where seagrass recovery approximately started.

also show a significant decrease only in the southern Wadden Sea (multiple regressions with riverine TN input and autumn chlorophyll as independent factors). Spatial gradients of both proxies (summer chlorophyll or autumn NH_4 + NO_2 2002 - 2006) show generally higher values in the southern than in the northern Wadden Sea.

A decrease in eutrophication status now is evident. European legislation (Water Framework Directive), however, prescribes that a good status has to be reached in 2015. Currently, no agreement has been reached on a trilateral level on yet on reference conditions and on boundaries between the high, good and moderate status. A general approach is to use fixed metrics with reference conditions as a starting point. But from a holistic point of view such fixed metrics do not necessarily make sense and mostly are not based on ecological considerations. In the present paper, I will suggest an alternative approach by exploring the discontinuities that occurred or may have occurred during the shift towards a eutrophic Wadden Sea and by putting these continuities into perspective. I exemplify this for the northern Wadden Sea.

2. Quality components and indicators of coastal eutrophication

The Water Framework Directive prescribes three quality components for coastal waters being Phytoplankton (biomass and species composition), macrobenthos and macrophytes. A good quality indicator should correlate with the main driver of coastal eutrophication being riverine nutrient input (van Beusekom *et al.*, 2005). I will focus on mean summer chlorophyll levels as this proxy proofed to be a useful eutrophication indicator for the entire Wadden Sea. I will put discontinuities in phytoplankton species composition and in seagrass occurrence in perspective to the relation between summer chlorophyll and riverine nitrogen input thus providing a more holistic view on Wadden Sea eutrophication. I will not consider macrobenthos as up 'til now, no clear relation between nutrient loads and macrobenthos biomass and species composition is evident (van Beusekom *et al.*, 2001).

3. Temporal development of eutrophication quality components

Phytoplankton biomass

Longest phytoplankton time series in the northern Wadden Sea are from the List tidal basin. A significant correlation is found between riverine TN loads and summer chlorophyll (Fig. 2). Variability is high and a linear regression only explains about 30% of the observed variability (van Beusekom *et al.*, 2009). The dashed lines indicate the maximum and minimum values between which the summer chlorophyll values vary at a given riverine TN input. The lines converge at low riverine input levels near close to the estimated background levels of ~1.5 µg Chl-a/l (van Beusekom, 2005). Despite a range in riverine input of almost a factor of three, no indications are found other than a linear response to riverine nutrient loads. Also the range of chlorophyll values at a given input decreases proportional to the river load as indicated by the dashed lines. I conclude from this, that no apparent discontinuities in the response of the summer chlorophyll levels have taken place.

Phytoplankton species composition

Phytoplankton succession in the list tidal basin is characterized by a Si limited spring bloom dominated by diatoms (requiring Si for their frus-

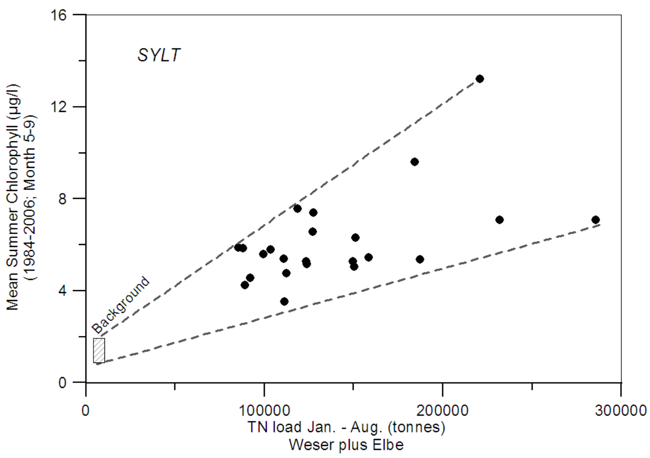

Figure 2: The relation between mean summer chlorophyll (May–September) in the List tidal basin and riverine Total Nitrogen load (January – August) via the rivers Weser and Elbe (van Beusekom *et al.*, 2009). Dashed lines indicate the maximum and minimum values of summer chlorophyll at a given riverine TN load. The background estimate is after van Beusekom (2005).

tules) and a NO_3 limited *Phaeocystis* bloom that do not need Si (Loebl *et al.*, 2007; van Beusekom *et al.*, 2009) (Fig. 3). The role of Si in changing the species composition as a response to coastal eutrophication was already discussed by Officer and Ryther (1980). I conclude from this, that with increasing riverine TN loads the phytoplankton dynamics must have changed from a former N limited diatom spring bloom (excess Si left over after the bloom) to an Si limited spring bloom (with excess NO_3 left over after the bloom). This transition marks a discontinuity in the eutrophication history of the Wadden Sea that may be used as an objective benchmark when setting goals for reducing N loads into the Wadden Sea and adjacent coastal zone.

In the following I will give an estimate of the river TN concentration at which a transition from a present day Si-limited spring bloom to an N limited spring bloom may occur. Diatoms can use a wide range of Si concentrations, but as a global average, Brzezinski (1985) mentions an Si:N ratio of 1:1. In coastal waters we may thus expect N limited spring blooms when Si:N ratios in winter (shortly before the onset of the spring bloom) are about equal.

Dissolved Inorganic Nitrogen (DIN) is the dominant N species in the rivers Elbe and Weser and in the German Bight. Both DIN and Si behave conservatively. In winter, the ratio between Si and DIN is about 0.6. This implies that DIN concentrations in the rivers have to be lowered by 40% to reach an Si:DIN ratio of about 1:1. Present day loads are in the order of 144 kTonnes N/year implying a reduction to 86 kTonnes/year. This is a first estimate not taking in account factors like denitrification or additional Si sources through the dissolution of river borne frustules from freshwater diatoms (*e.g.* Conley, 1997)

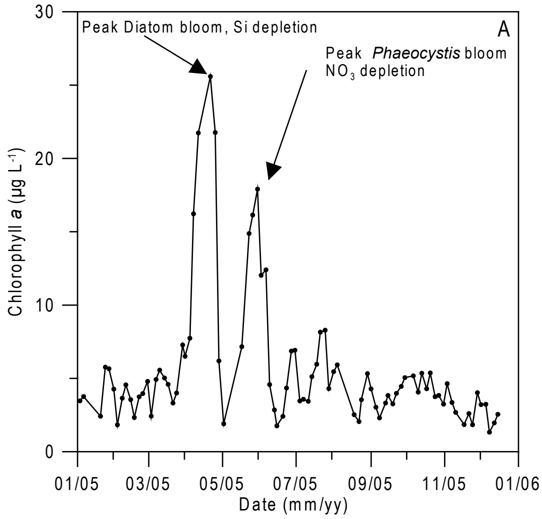

Figure 3: Seasonal dynamics of phytoplankton succession during the spring diatom bloom and the ensuing *Phaeocystis* bloom.

Seagrass and green macroalgae

Macrophytes are quality indicators of coastal eutrophication and are used in the WFD assessment. Whereas seagrasses have declined worldwide due to eutrophication (Burkholder *et al.*, 2007), green macroalgae have benefited from coastal eutrophication (Fletcher, 1996). Green macroalgae coverage recently declined in the northern Wadden Sea and a significant correlation with riverine nutrient loads was found (van Beusekom *et al.*, 2009) excluding the year 2001. The data show a large variability (and one outlier), but the response to the decreasing riverine loads is linear. Macroalgae coverage does not show a discontinuous response to riverine nutrient loads. Seagrass strongly declined since the 1930's among others because of the wasting disease in the 1930's and eutrophication (Reise *et al.*, 2008). Since the mid 1990's seagrass is recovering in the northern Wadden Sea (Fig. 4) (Reise and Kohlus, 2008). The recovery started during a series of dry years with low riverine TN loads. This period is indicated in Figure 1.

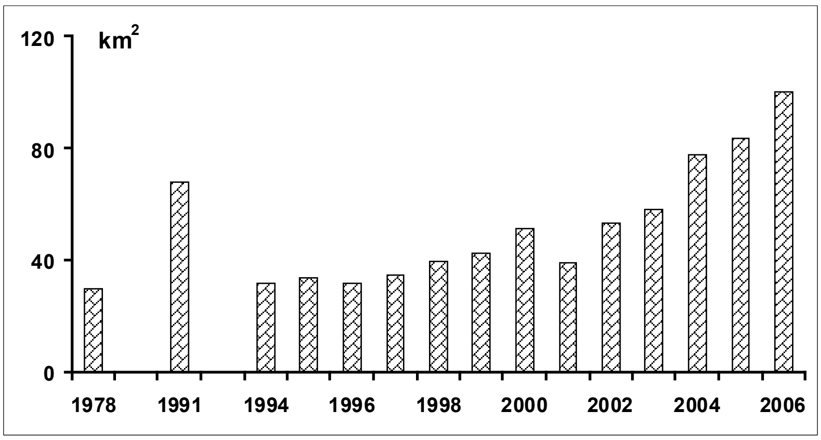

Figure 4: Seagrass recovery in the northern Wadden Sea (from Reise and Kohlus, 2008).

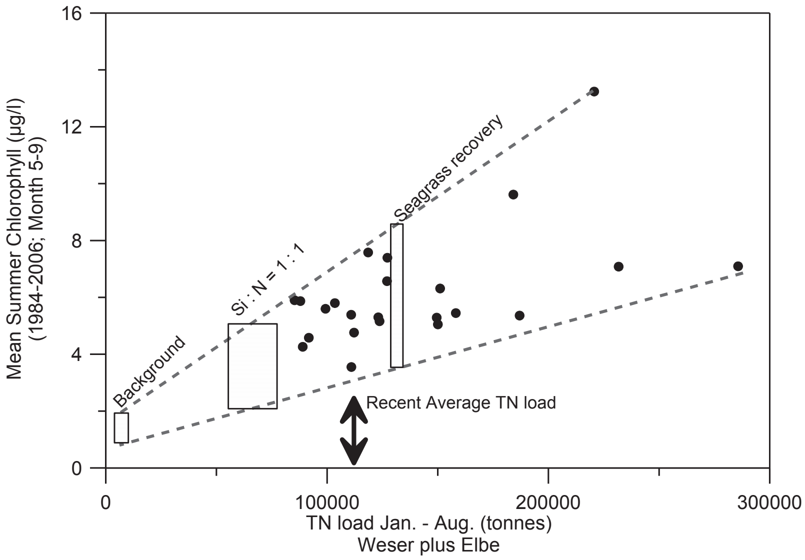

Figure 5: A tentative holistic approach relating seagrass recovery and shift from N to Si limited spring blooms with riverine TN loads. Note that the X-axis shows riverine loads from January-August. Annual loads are about 30% higher.

4. Discontinuities: a more holistic approach toward defining a good ecological status?

In the previous chapters I explored discontinuities in the response of the northern Wadden Sea to changing nutrient loads. Four quality components were discussed: Phytoplankton biomass, phytoplankton composition, green macroalgae and seagrass. In this chapter I will put the changes observed in these quality indicators in perspective to riverine TN loads as a first step towards a more holistic assessment of Wadden Sea eutrophication. As a starting point I used the relation between summer phytoplankton biomass (as chlorophyll) and riverine TN loads (January-August). Pinpointing changes in the response of the Wadden Sea ecosystem to certain riverine nutrient loads may help in formulating more objective criteria for setting riverine nutrient reduction goals.

Mean summer phytoplankton biomass is a good indicator of the eutrophication status but present knowledge indicates a linear response to riverine TN loads. Thus, this proxy does not give clues on sudden changes in the response of the Wadden Sea to changed nutrient loads (Fig. 5). It does however highlight the relation between eutrophication and riverine TN loads and is used here as a template against which the other quality indicators are projected. Green macroalgae coverage is correlated to riverine TN loads but no discontinuity in the response is obvious. As such, green macroalgae cover is a good eutrophication indicator but the lack of discontinuous precludes the use for formulating objective reduction goals.

After a loss of seagrass since the 1950's (Dolch, pers. comm.) seagrass is recovering since the mid 1990's. The riverine loads during the onset of the recovery have been tentatively indicated in Figure 5.

Phytoplankton composition also shows a clear discontinuity. Spring diatom blooms nowadays are Si limited but probably were N limited during pre-eutrophicated times. This discontinuity can be tentatively linked to riverine TN loads assuming that coastal diatoms take up Si and N in an approximately ratio of 1:1. The riverine load needed for a balanced Si:N ratio is about 40% below present day levels (2001-2006).

In summary, two major discontinuities in the eutrophication history of the northern Wadden Sea could be identified and linked to riverine nutrient loads being seagrass cover and the transition from Si to N-limited spring diatom blooms. These discontinuities can be used to define 1) more objective goals of a good ecological status and 2) help in formulating measures to reach these goals.

The riverine TN loads have decreased during the past decades and contributed to the seagrass recovery since the mid 1990's. However, phytoplankton dynamics are still shifted toward Si limited spring blooms. At least a 40% reduction in riverine TN loads is necessary to reach this goal.

As a next step, the above approach should also be developed for the southern Wadden Sea. It has been suggested that the southern Wadden Sea has a higher eutrophication status than the northern Wadden Sea (van Beusekom, 2006). The absence of major seagrass meadows is in line with this. Whereas Si based reduction goals can be formulated quite easily, it will be a major challenge to estimate riverine reduction measures that will enable seagrass recovery in the southern part of the Wadden Sea.

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Salt marshes: applied long-term monitoring

K.S. Dijkema* , A.S. Kers ** & W.E. van Duin *
* Wageningen IMARES (Institute for Marine Resources and Ecosystem Studies), Texel, NL
** Rijkswaterstaat DID (Data-ITC-Dienst), Delft, NL
Kees.Dijkema@wur.nl

1. Introduction

Time series of vegetation succession, sedimentation and relative water levels (high tide fluctuations and soil subsidence) in Netherlands salt marshes (Table 1) provide sound data for conservation strategies, site management and impact assessment (Bakker *et al.*, 2005).

2. Methods for time series in salt marshes

2.1 Transects Ameland and Peazemerlannen (14-22 years)

The monitoring includes 4 transects of ca. 1 km long from sand dunes or seawall to intertidal flats. The transects include 60 permanent plots of 2 x 2 m for sedimentation measurements twice a year, vegetation recording annually and elevation every 2 years. Sedimentation is recorded with a 17 pins SEB (Sedimentation Erosion Bar; Figure 1) with a 95 % confidence interval of ca. 1.5 mm (Boumans and Day, 1993).

2.2 Transects Friesland and Groningen mainland (50 years)

25 experimental fields of ca. 50 ha are monitored along 50 km mainland coast of The Netherlands Wadden Sea. Each field includes ca. 50 fixed 100 m transects for levelling at 4 year intervals and ca. 50 permanent plots of 100 x 100 m for yearly vegetation recording. For elevation and accretion each mean record from a fixed 100 m transect has a confidence interval of ca. 1.5 mm (Dijkema, 1997; Dijkema *et al.*, 2001, 2009).

Years	Scale	Location	Monitoring Goal	Organisation
30	1:5/10,000	All NL salt marshes	Area + biodiversity	Rijkswaterstaat DID
50	2 regions 25 transects	Friesland & Groningen mainland	Restoration	Rijkswaterstaat & LNV & IMARES Texel
22	2 sites Transects	Ameland barrier island	Effect of soil subsidence due to gas extraction	IMARES Texel & NAM
14	2 sites Transects	Peazemerlannen mainland & summerpolder	Autonomous development (from 2007: effect soil subsidence)	IMARES Texel & NAM

Table 1: Time series in salt marshes in The Netherlands discussed in this paper.

2.3 Vegetation mapping of all salt marshes (30 years)

Mappings are made at scale 1:5000 or 1:10,000 with 6-year intervals. Input is from remote sensing (interpretation of stereo false-colour photographs) and fieldwork. For the classification of vegetation, a standard typology is used (SALT97, de Jong *et al.*, 1998).

3. Sedimentation and sea level rise

Sedimentation is both related to large-scale zonation (mainland; Figure 2) and to small-scale patterns (barrier island Ameland; Figure 3) and is also events-driven (*e.g.* storm). The distance to sediment sources (creeks, sea) and local drainage

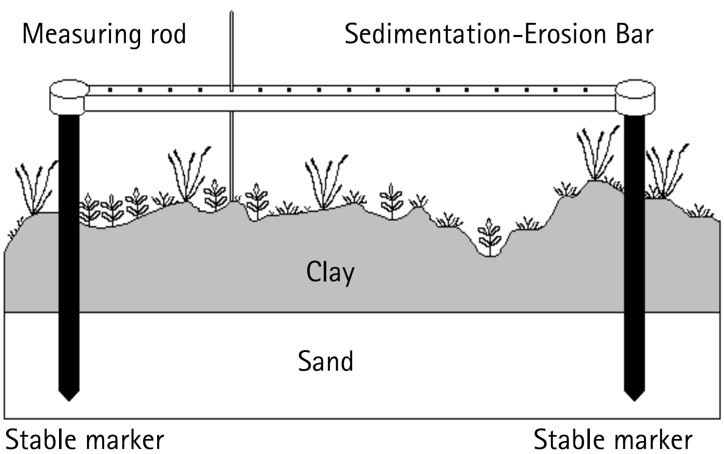


Figure 1: 17 pins Sedimentation Erosion Bar (SEB).

Figure 2: Peazemerlannen de-embanked summer-polder, showing effects of zone-elevation on sedimentation (SEB means). Salt marsh sedimentation is 10-22 mm/yr, summerpolder < 0 mm/yr. A winter with lower tides due to easterly wind (1995-1996) shows no sedimentation and 2 winters with stormfloods (2006-2008) show the positive effect of such events.

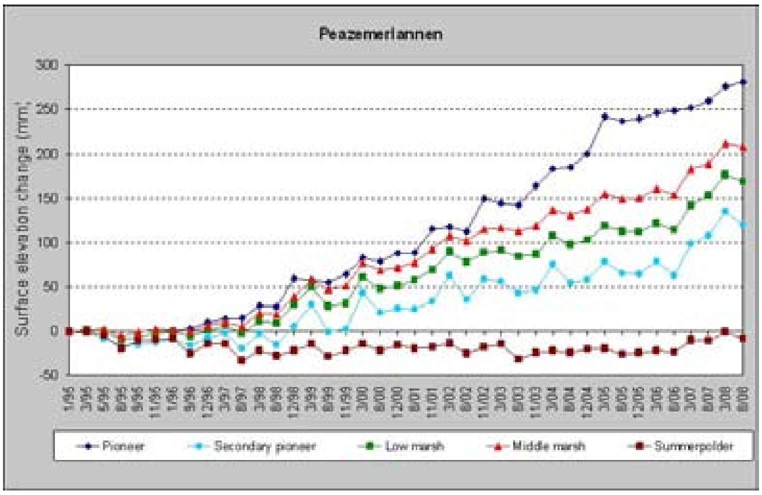
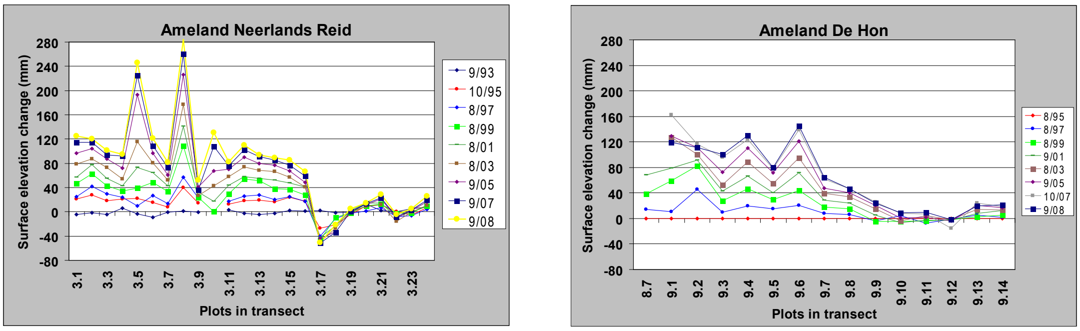


Figure 3: Ameland barrier-island sedimentation (2 SEB transects). Plots left in both graphs are close to the Wadden Sea, showing the effect of sediment source (plots right are close to sand dunes). Proximity of a tidal creek, low marsh elevation and storm-events also increase sedimentation. Soil subsidence of ca. 110 mm in the monitoring period was fully compensated in the seawards plots only. But there was hardly any effect of lowering marsh surface on the salt marsh vegetation (chapter 5).



patterns are similar important. Vertical salt-marsh zone sedimentation rates for the mainland are double those on the barrier-islands and may for most sites keep pace with a sea-level rise accelerated to 10 mm/y.

Vertical accretion in the salt-marsh zone is a natural process leading to higher salt marshes. The accretion in man-made mainland salt marshes is the highest, with 1.3-2.0 cm/y (Table 2). The vertical accretion should decrease as higher salt marshes get fewer tidal floodings, but from 2000 on, salt marsh accretion increased again (Figure 4), possibly because of an increasing number of storm tides (Dijkema *et al.*, 2009). Sediment budget measurements in Peazemerlannen (Van Duin *et al.*, 1997) showed that one such storm event may import 125 times the amount of sediment compared with a normal tide.

4. Salt marsh area restoration

Mainland salt marshes in the international Wadden Sea are mainly anthropogenic in origin, stimulated by a system of drainage ditches, and since the 1930s by a lay-out of sedimentation fields surrounded by brushwood groynes. Conditions for sedimentation and plant establishment were both improved, forming a man-made landscape of high value. The Netherlands sedimentation fields originally measured 400 x 400 m, arranged in three rows from the salt marsh onto the intertidal flat. Vertical sedimentation in the pioneer zone is critical, hampering in periods with insufficient maintenance of the brushwood groynes (Figure 4). The 50-year monitoring series of mainland salt marshes taught us how to restore the pioneer zones to a successful defence zone against erosion for the benefit of both the salt marsh and the coastal zones (Dijkema *et al.*, 2001, 2009).

Table 2: Vertical accretion Friesland and Groningen mainland, average of 25 experimental fields.

	3rd fields Bare mud	2nd fields Bare mud	2nd fields Pioneer zone	1st fields Salt marsh zone
Friesland mainland 1992-2007	0.3 cm/y	1.1 cm/y	2.4 cm/y	2.0 cm/y
Groningen mainland 1992-2007	0.1 cm/y	0.7 cm/y	0.7 cm/y	1.3 cm/y

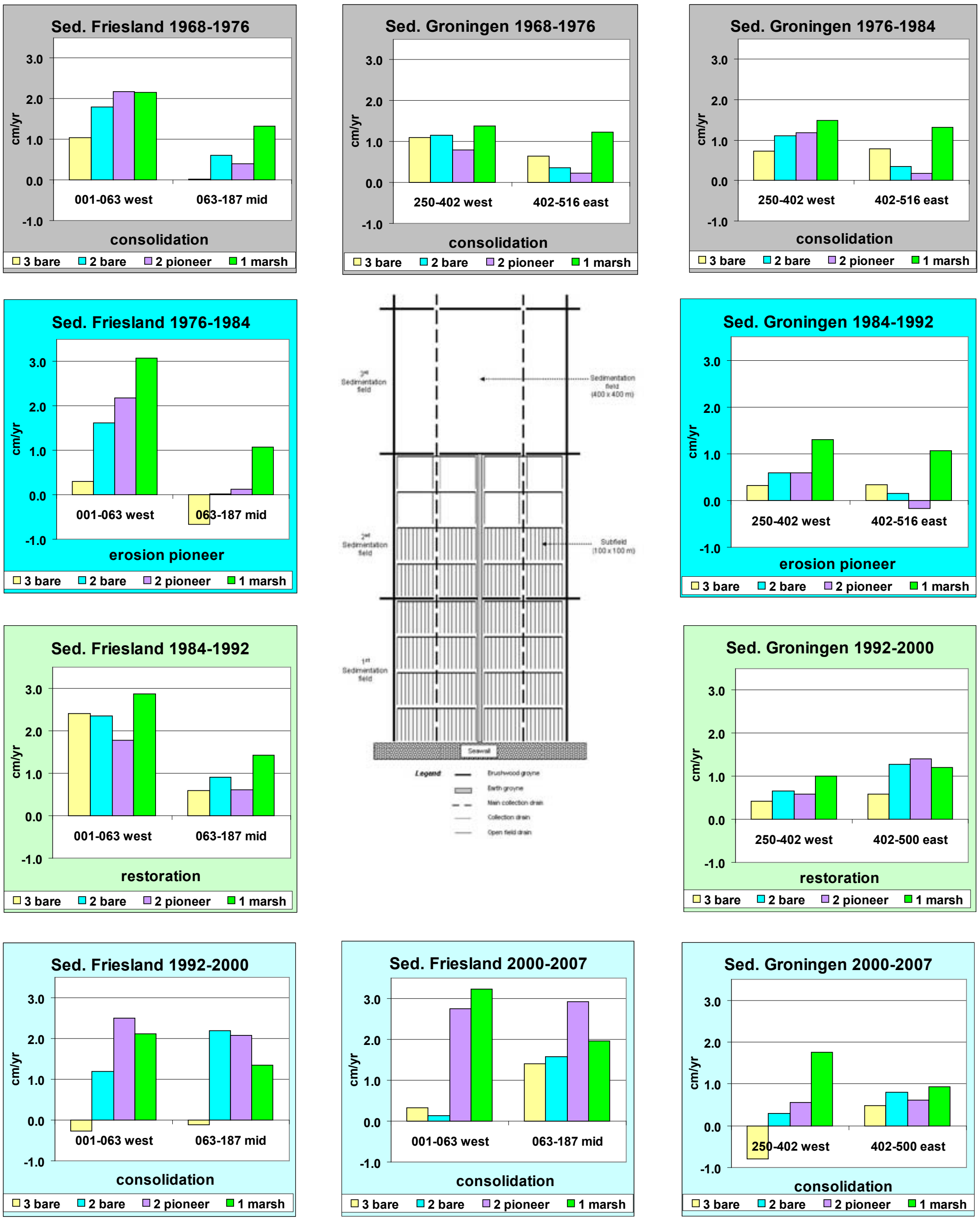


Figure 4:
Vertical accretion in both Friesland and Groningen mainland salt marsh zones is at an all time high. However, the pioneer zone needs artificial protection against waves and currents. All sedimentation fields renovated since 1989 (W-E fetch reduced to 200 m and building new brushwood groynes at the original 0.30 cm + MHT) show a positive accretional balance today. Compare Friesland-mid before and after 1984 and Groningen-east before and after 1992.

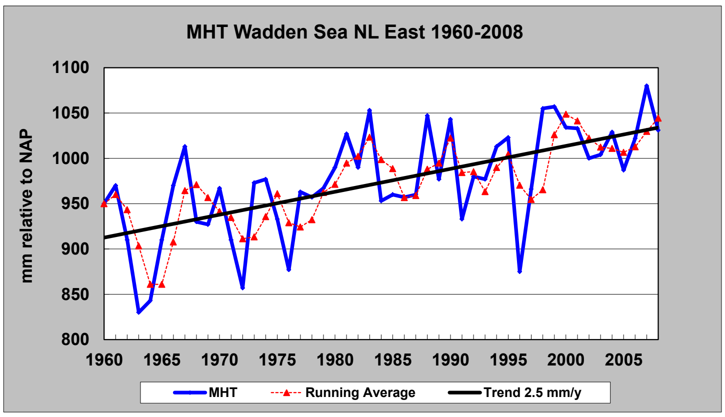


Figure 5:
Yearly average MHT-levels in the eastern Wadden Sea, The Netherlands (mean value of the tidal stations Nes, Lauwersoog and Schiermonnikoog). Note the trend in MHT-rise of 2.5 mm/y. The large year-to-year difference is explained by wind force, wind direction and air pressure (Bossinade *et al.*, 1993).

- Sedimentation fields should be constructed only under certain prerequisites. The elevation in the upper tidal zone is from about 0.5 m below MHT onwards. The third, most seaward row of sedimentation fields, which did not contribute to protection, was abandoned.
- Sufficient sediment availability is an important condition. The currents in the area must be low enough to allow sedimentation in the fields. Engineering measures, on sites where either the accretion rate was very high or where elevations stayed too low to allow salt marshes to develop, were finished.
- The establishing of sedimentation fields has ensured the presence of an extensive pioneer zone. The pioneer zone itself protects the salt marsh higher up. There is no other need for additional protection measures in the salt marsh zone. A reduction in size of sedimentation fields in the pioneer zone to 400 x 200 m or to even 200 x 200 m to lower the wave fetch at sites where elevation development of the pioneer zone did not keep pace with the MHT-rise and where the low salt marsh deteriorated.
- All remaining groynes were restored to the original construction height of 0.30 m above MHT, with an extra margin for future sea-level rise (Figure 5). Use of durable brushwood filling (*Picea abies*, *Pseudotsuga menziesii*, *Picea sitchensis*) allowed a lower filling frequency, and meant a cut in maintenance costs.
- To allow natural creek systems to form, no groundwork should be carried out within sedimentation fields. This is a prerequisite for a natural salt marsh development even within man-made salt marshes. Groundwork does not enhance the sedimentation rates within sedimentation fields (Dijkema *et al.,* 1991, Michaelis *et al.,* 2008). All groundwork on the drainage system was finished after 1997, without impact on vertical accretion. As a consequence, constant monitoring and maintenance of a solid connection between brushwood groyne and salt marsh is necessary to prevent erosive water currents forcing their way through.
- Cliff erosion of salt marshes is a natural process, both in naturally establishes marshes as and man-made salt marshes. In an extended salt marsh, sedimentation fields should not be constructed because natural processes should be allowed to work. If cliff erosion has to be stopped, only two courses of action are recommended. The most nature-friendly one is the construction of a new sedimentation field in front of the cliff. Only under very extreme conditions should stone revetments established *e.g.* around the Halligen.
- There is no need and no intention to restore an entire border of salt marshes along the entire Wadden Sea coast, nor should sedimentation fields be constructed at the edge of natural salt marshes to extent the marsh. The construction of sedimentation fields would transform one highly valued natural feature – the tidal flats - into another one. For the same reason we advised against hydraulic filling for „salt marsh building" or as a

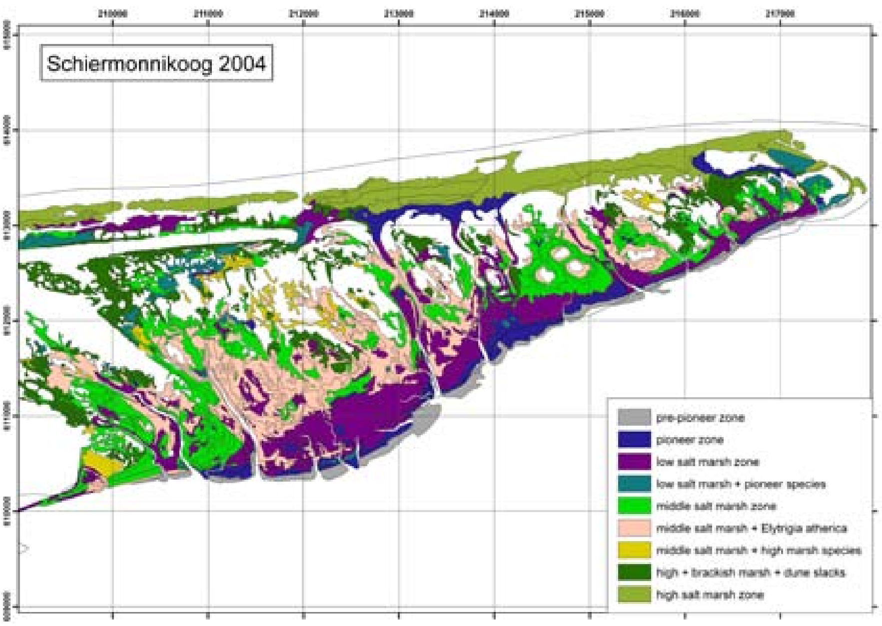


Figure 6: Vegetation map of the barrier-island Schiermonnikoog as an example of the Trilateral salt marsh aim: a vegetation biodiversity reflecting the geomorphological conditions of the habitat.

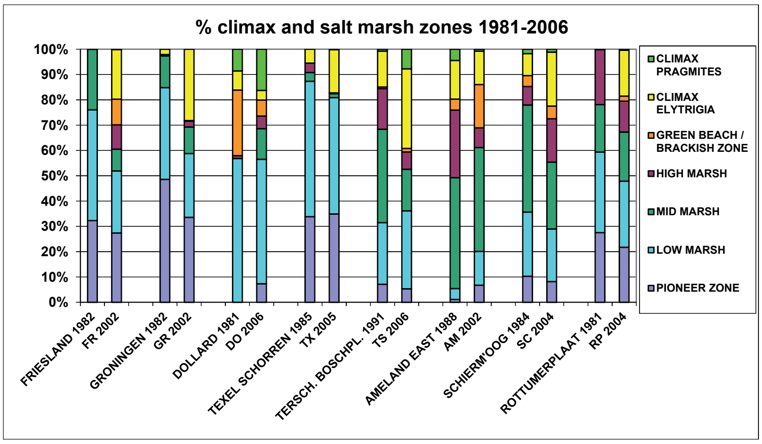


Figure 7: Comparing vegetation maps of RWS-DID (Dijkema *et al.*, 2007).

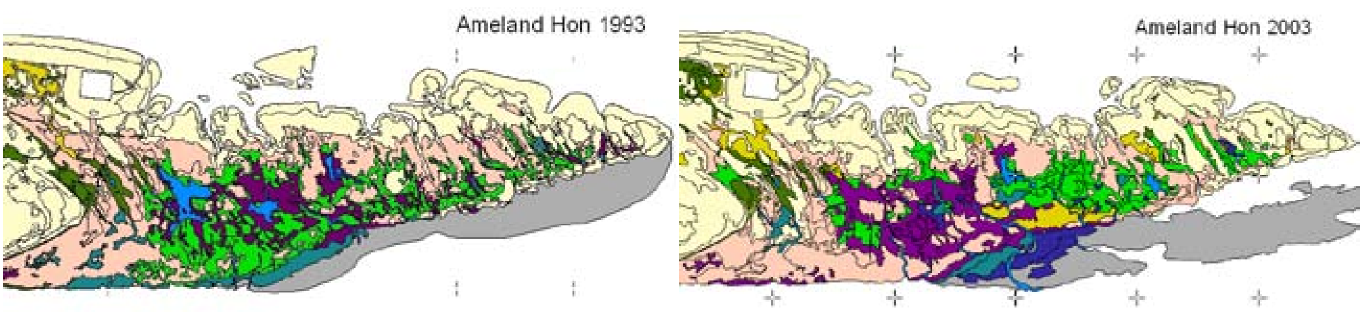
protection measure. The only exception is for dike protection in the future to counteract an increased sea level rise *e.g.* for restoration of the 30 km long Afsluitdijk with a sustainable salt marsh in front of the dike.

5. Vegetation succession and biodiversity

Monitoring with vegetation maps is essential for scaling-up of the transect method. Sequential vegetation maps show the development of the entire marsh area and its vegetation biodiversity (Figure 6). A 30-year series of vegetation maps of all salt marshes in The Netherlands and the estuarine Dollard marshes shows that vertical sedimentation triggers vegetation succession to older stages with less biodiversity. The autonomous aging process is accelerated on creek levees, on salt marshes without cyclic processes (sand-dike or groyne protected) and on drained mainland marshes (Figure 7; Dijkema *et al.*, 2007). The distribution of vegetation zones and succession climax stages is still diverse. Due to succession, the area of climax-vegetation has increased; on the islands, the high marsh zone decreased and on the mainland coast, the low marsh zone decreased. Groningen and Friesland mainland shows the highest increase of *Elytrigia* climax due to highest figures for sedimentation (Friesland) and strongest decrease in grazing (Groningen). In the Dollard, the *Elytrigia* climax has decreased, caused by an overall grazing management and by rewetting due to ditch-blocking in the eastern segment; grazing is not enough to stop the increase of the brackish *Phragmites* climax (Esselink, 2000). On the barrier islands, *Elytrigia* climax increases on Texel, Terschelling, Schiermonnikoog and Rottumerplaat. *Elytrigia* climax has the highest share on the oldest sand-dike protected salt marsh Boschplaat, on the barrier-island Terschelling. On the barrier-island Ameland, heavy grazing and soil subsidence slow down succession. The most important sites for the pioneer zone are the Friesland and Groningen mainland salt marsh works.

A 22-year period of 1.5 mm/y soil subsidence on Ameland had ver little effect on the salt marsh vegetation (Figure 8). The maps show a 10 ha regression in salt marsh basins with a relative large distance to the sediment source (central part, from green middle marsh to purple low marsh). The other parts show 20 ha autonomous succession to *Elytrigia atherica* climax (rose) and even 5 ha new marsh growth (central south part, dark

Figure 8: Comparison of vegetation maps of 1993 and 2003 from the soil subsidence area De Hon on the barrier-island Ameland.



blue). Most remarkable is the succession from a 2.4 ha water-filled basin (left part, blue) to low marsh zone (pink) after natural connection of the basin to a creek. The hypothesis of Dijkema *et al.* (1990), that a delay in the regression of salt marsh vegetation after soil subsidence and/or sea level rise allows an increased vertical accretion to compensate for the subsidence of the marsh surface, may come true. Year-to-year fluctuations in MHT-levels, and especially years with raised average MHT-levels, may contribute to this compensation mechanism (Figure 5; Dijkema *et al.*, 2007). Aging is decreased by soil subsidence (and/or sea-level rise; Figure 7).

6. Conclusions

Vegetated salt marshes are sustainable habitats in present scenarios for sea level rise and subsidence due to gas extraction:

- Management measures should focus on (1) upkeep of mainland pioneer zone for protecting the marsh edge and (2) allowing more dynamics on the barrier island marshes.
- Recommendations for restoring pioneer zones to a successful defence zone against erosion of both salt marsh and coastal zones were based on a 50-year monitoring series.
- The present man-made marsh-renewal technique is an opportunity for coastal defence, *e.g.* for restoration of the 30 km long Afsluitdijk with a sustainable salt marsh in front of the dike.
- The trend in vegetation succession is aging from young marsh to climax vegetation, leading to a decrease in young successional stages and in biodiversity:
- Management measures should focus on rejuvenation of salt marsh vegetation.
- The TMAP trilateral salt marsh aim "Biodiversity reflecting geomorphological conditions" means that management should not be reached by "gardening".
- We recommend the development of a biodiversity measurement tool using the new TMAP-classification.

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Evaluation of blue mussel beds in the North-Frisian Wadden Sea - according to the EU Water Framework Directive and EU Habitats Directive

Heike Büttger[1], Torsten Berg[2], Georg Nehls[1],
h.buettger@bioconsult-sh.de (corresponding author), berg@marilim.de, n.nehls@bioconsult-sh.de
[1]BioConsult SH, Brinckmannstr. 31, D-25813 Husum, [2]MariLim Gewässeruntersuchung Kiel, Heinrich-Wöhlk-Str. 14, D-24232 Schönkirchen

1. Introduction

Mussel beds are special, characteristic and long living surface and near-surface habitats within the Wadden Sea. They provide a habitat for many endobenthic as well as epibenthic species. Diversity and biomass is higher on mussel beds than on the surrounding tidal flats. Within the dynamic Wadden Sea, mussel beds are stable structures that can survive over decades at the same site. Changes which might affect the macrobenthic community become apparent on long-established mussel beds.

The assessment of the conservation status within such a highly dynamic environment as the Wadden Sea is a challenging task as it requires detecting sometimes subtle changes against the background of a high natural fluctuation. The Wadden Sea is a shallow fringe of the North Sea where fluctuations of the climatic conditions as winter temperatures or storm events exert much stronger impacts than in the North Sea itself. Annual temperature fluctuations are almost two times higher than in the central North Sea and irregular changes between mild winters and extensive ice cover may induce significant variations in the benthic communities (Reise, 1985). Likewise storm events, which have shaped the morphology and hydrology of the Wadden Sea throughout its history, structure benthic communities through direct physical forces. The spatial extent and the structure of intertidal benthic communities of the Wadden Sea thus shows much stronger annual fluctuations than in open marine waters where such effects are absorbed in a large water body.

The Wadden Sea is different from many other marine waters in a very important aspect: sheltered areas are sedimentation areas where enrichment with detritus and nutrients is a characteristic process, leading to a natural 'eutrophication'. Thus, any assessment of the ecological status of benthic communities of the Wadden Sea must be based on a solid description of their characteristics and their extensions. In this respect, mussel beds offer a marked advantage as their annual and long-term dynamics can be easily and accurately assessed and quantified, because the epibenthic structures of the mussel beds could be easily distinguished from other benthic communities.

According to the EU Water Framework Directive (WFD), all member states have to bring their water bodies (including the German coast of the Wadden Sea) into a good ecological state by 2015. Already the Wadden Sea Quality Status Report 2004 (Essink *et al.*, 2005) mentioned that "The biotope 'intertidal blue mussel bed at stable sites' should be considered within the WFD as a biological quality element for coastal waters". The continuing mussel monitoring in the National Park of the Wadden Sea Schleswig-Holstein offers more than ten years of data, which is a good basis for an initial assessment of the WFD evaluation criteria.

Furthermore, blue mussel beds are a characteristic feature of the habitat type 1140 "mudflats and sandflats" under the Habitats Directive (HD). The HD demands the maintenance of favourable conservation status of specified habitat types, including 1140 and its mussel beds.

This paper presents an approach to the assessment of blue mussel beds within the terms of the WFD, which will also meet the requirements of the HD.

2. Approach to derive references

Structural parameters (*e.g.* number of mussel beds, age structure, biomass, stability of mussel beds and others) are reviewed for an evaluation of the ecological status and references for the high ecological status will be given.

The evaluation of the associated community of mussel beds as required by the WFD is examined by using the index-tool MarBIT, a system developed by MariLim (Kiel) for the Baltic Sea (Meyer *et al.*, 2008).

3. Structural parameters

3.1 Mussel bed area and steadiness of sites

The analysis of aerial photographs from 1958 identified 126 blue mussel beds covering an area of about 750 ha. Information about comparatively small mussel harvests in the 1950s (Seidel, 1999), the lack of fishery traces on intertidal mussel beds (with one exception) on the aerial pictures, the absence of ice winters in the years before 1958 (pers. comment BSH, 2008) and statements about the general development of mussel stocks in the Wadden Sea (Reise *et al.*, 1989; Michaelis, 1987), lead to the conclusion that mussel stocks in 1958 have not been unduly affected. Therefore, the digitalized mussel bed area in 1958 is assumed to be within a typical range and these data are used as a measuring point to determine references of mussel bed area and stability of sites.

The reference value of the total mussel bed area was calculated as a mean value of the years 1958, 1988-1994 (Ruth, 1994; Stoddard, 2003) and 1998-2001, which results in a mean value of 991 ha. As eutrophication is likely to support blue mussels, a strong increase of mussel bed area is regarded as negative and leads to downgrading within the WFD evaluation.

To assess stability of sites, we define steadiness of sites which were found in nearly all years (at least in 11 years), which were found in 1958 or in 1989 and in at least in five years of monitoring between 1998 and 2007. Sites which were populated in all years during the monitoring (1998-2007) but not in 1958 or 1989 are also included. Using these criteria, it follows that 63 sites should be populated by blue mussel beds regularly. The WFD covers six years for every evaluation period, which means that all sites could be populated 378 times at best.

3.2 Biomass

Biomass of the mussel beds is determined mainly as live-wet-weight (LWW), which is calculated by using the formula lnLWW= 2,919ln (length in mm)-8,764 (Nehls 1995). As mussel bed area and locations in 1958 are not obviously different from data obtained in 1989 and between 1998 and 2001, it can be assumed mussel beds have a similar ecological status and no marked change of the baseline occurred until 2001. Therefore we suggest using data between 1998 and 2001: the frequency distribution indicates the median value of LWW as 12.4 kg/m^2 in these years and we use this as the reference point. As eutrophication is likely to support blue mussel biomass, increasing mussel biomass leads to downgrading in the evaluation.

3.4 Flesh content

Flesh weight is determined from a sub sample for each mussel bed to obtain a condition-index (a-parameter, without any dimension). The calculation is done using the program MUSSEL (Brinkman 1993) and bases on the function WF=a*Lb (WF = cooked flesh weight, L = length of the mussel in mm, b = constant with 2.8). Using data from all size classes could lead to decreasing trends of flesh-content in response to the age structure, but would not reflect environmental changes. Therefore we recommend using a limited size group from 20 to 49 mm and selected mussel beds which are monitored continuously. Because the a-parameter of 20 to 49 mm mussels did not show a general significant trend in the monitoring until 2006 (Nehls and Büttger, 2009), seasonal reference values are determined as the mean values of the years 1998-2006.

3.5 Other parameters

Further parameters like density, age-structure (cohorts) or spatfall occurrences and maximum shell-length were evaluated, but due to high variability between years, seasons or mussel bed sites, we do not recommend to use these parameters for an evaluation. These parameters are reflected by the four recommended parameters. For instance, sufficient spatfall would be apparent in steady or increasing mussel bed area and mussel biomass.

3.6 Recommendations for reference values and evaluation of changes

Considering the different parameters presented, we recommend the reference values listed in Table 1 which refer to the North-Frisian Wadden Sea of Schleswig-Holstein. Mean values of the parameters for the first evaluation period 1998-2003 are converted into linear ecological quality ratios (EQRs) from bad (0) to highest status (1) according to the procedure of Meyer *et al.* (2008). The overall status is calculated as mean value of the four EQRs.

3.7 Exemplary assessment

For the first monitoring period 1998 – 2003 the conservation status is classified as green (Table 1). For the second period (2004-2009) the data from 2004 – 2007 indicate a worsening situation.

These proposed references refer to the North-Frisian part of the Wadden Sea of Schleswig-Holstein. As the number and stability of sites and area is much smaller in Dithmarschen, references and class limits for structural parameters could hardly be defined. The WFD requires evaluations of different water bodies. But mussel beds do not occur in all water bodies. It will not be possible to define references and evaluate each water body separately by using structural parameters of mussel beds.

Table 1:
Proposed reference values for the parameters 'area', 'biomass', 'steadiness of sites' and 'condition' in order of an evaluation of the North-Frisian Wadden Sea of Schleswig-Holstein according to the WFD. Resulting EQRs for the first monitoring period 1998-2003 are given.

	Reference	High	Good	Moderate	Poor	Bad	1998-2003	EQR
Area [ha]	990 ha	2000 ≥ 990	2250 ≤ 991 or 989 ≤ 750	2500 ≤ 2251 or 749 ≤ 500	2750 ≤ 2501 or 499 ≤ 250	>2751 or <249	757	0,606
Steadiness	63 sites (in all six years 378 x)	378 – 340 (≤10%)	339 ≤ 291x *(11 ≥ 25%)*	290 ≤ 189x *(26 ≥ 50%)*	188 ≤ 95x *(51 ≥ 75%)*	95 ≤ 0x *(≥ 76%)*	306 x	0,663
Biomass [LWW in kg/m²]	12,4	20 - 12,4	12,3 ≤ 9,4 or 25 ≥ 20,1 *(± ≥ 25 %)*	9,4 ≤ 6,2 or 25,1 ≥ 30 *(± 26 ≥ 50%)*	6,2 ≤ 3 or 30,1 ≥ 35 *(± 51 ≥ 75%)*	2,9 ≤ 0 or ≥ 35,1 *(± ≥ 76%)*	11,9	0,772
Condition (a-parameter, 20 -49mm)	Winter 2.48E-05 Spring 3.23E-05 Summer 3.84E-05 Autumn 3.86E-05	*± 10%* 3.12E-05 ≥ 2.55E-05 3.55E-05 ≥ 2.90E-05 4.02E-05 ≥ 3.29E-05 4.07E-05 ≥ 3.33E-05	*11 ≤ 20%* ≥ 2.27E-05 ≥ 2.58E-05 ≥ 2.92E-05 ≥ 2.96E-05	*21 ≤ 30 %* ≥ 1.99E-05 ≥ 2.26E-05 ≥ 2.56E-05 ≥ 2.59E-05	*30 ≤ 40 %* ≥ 1.70E-05 ≥ 1.94E-05 ≥ 2.19E-05 ≥ 2.22E-05	*> 50%* ≥ 1.42E-05 ≥ 1.61E-05 ≥ 1.83E-05 ≥ 1.85E-05	2.87E-05 3.40E-05 3.88E-05 3.90E-05	0,945
							Overall status	0,747

3.8 Transferability to the requirements of the Habitats Directive

Basing on the comparison of rating matrices according to the WFD and HD (proposal by M. Stock, Schleswig-Holstein Agency for Coastal Defence, National Park and Marine Conservation - National Park authority) we assume that the presented approach might me useable both in terms of the HD and WFD. The favourable conservation status (green, HD) can be considered as comparable to the good ecological status (WFD). The evaluation schemes for these two directives must be comparable.

4. Associated community – adoption of the MarBIT-tool

This chapter presents the MarBIT-tool assessment of the associated community of mussel beds in the Wadden Sea for the WFD. The tool is a multi-metric assessment system which uses four obligatory criteria: species composition, abundances, sensitive and tolerant taxa. The blue mussel monitoring provides macrobenthic data of mussel beds since 1999 and data until 2005 were used for this MarBIT test .

For each ecotope, a species reference list has to be derived, based on autecological information and which is the basis to determine references for species composition, sensitive and tolerant taxa. Each of these criteria is evaluated separately and merged in the EQR as mean. For more details about MarBIT please read Meyer *et al.*, (2008) and www.marilim.de/marbit/index.html.

4.1 Additions in MarBIT

As MarBIT was developed for the Baltic Sea, further additions had to be developed for its utilization on blue mussel beds in the Wadden Sea.

First, autecological information about all taxa which could occur potentially on mussel beds had to be added into the database. The ecotope "intertidal blue mussel bed in the Wadden Sea" was characterised with different parameters (habitat range intertidal; habitat salinity euhalin (N2) or polyhalin (N4), substrate-/habitat-requirements mussel bed, vertical habitat epibenthic or endobenthic; distribution range Wadden Sea, Schleswig-Holstein). Basing on the ecotope characterization, species reference lists are derived from autecological data.

4.2 Results

The reference lists for the ecotype N2 and N4 contain 53 taxa each, but species composition differs (without introduced taxa 49 and 47 respectively). As several introduced taxa occur on the reference list we also present the evaluation without Neozoa (defined as "Neozoa actualia" by Nehring and Leuchs, 1999).

An important aspect is the necessary amount of samples needed for a useful evaluation. About

70% (= 34 taxa) of the taxa on the reference list have to be found to obtain a 'good' status with MarBIT. This number could be found at best with 30-32 samples and is guaranteed from 47 samples upwards, therefore at least 50 samples for each water body are needed. A smaller number of samples might lead to an apparently 'moderate' status and would count as a methodical artefact. Therefore, macrobenthic data of each tidal basin were pooled for the evaluation.

4.3 Evaluation with the data-sets of the mussel monitoring

The overall evaluation resulted in good and moderate EQRs (Table 2). The evaluation of the Lister Deep does not change in general if Neozoa are in- or excluded from the species reference list. In the Norderhever, evaluation is worse in the first years and better in the last three years if Neozoa are included in the reference. Differences between including or excluding Neozoa from the evaluation become more obvious in the evaluation of the Norderhever where Neozoa are found seldomly in comparison to the Lister Deep. Mussel beds in the Lister Deep have been dominated by Pacific oysters (*Crassostrea gigas*) since 2003. Interestingly, in 2005 54% of all individuals found on one mussel bed in the Lister Deep belonged to introduced species (Büttger *et al.,* 2008), while on the second mussel bed the amount reached about 79%. However, EQRs in the Lister Deep did not change in particular since oysters and other alien species (e.g. *Crepidula fornicata, Elminius modestus*) became more abundant. Interannual changes of EQR values were highest for the index "abundances" in the Norderhever. Values range between poor and good. Changes are less pronounced in the Lister Deep. Furthermore, 2004 and 2005 the EQR for "sensitive taxa" dropped to poor conditions in both tidal basins. The indexes "diversity" and "tolerant taxa" are comparatively stable and range in most of the years within the 'good' status. But since 2004 "diversity" values dropped slightly and belong to the 'moderate' status in the Norderhever.

The EQR changes due to the relative fluctuations of the abundance distribution. This parameter is sensitive to changes and disruptions from a „smooth" distribution of species abundance to a more discontinuous situation, with few very abundant species and many species with a very low abundance.

5. Applicability of MarBIT and evaluation results

Basically, the application of the MarBIT-tool on blue mussel beds in the Wadden Sea seems to be possible. Basing on min. 50 samples per water body, the evaluation of five water bodies (where mussel beds occur) requires a total of 250 samples. To solve this problem between economy and the demand of the evaluation tool, an adapted (shorter) reference list might be possible. Taxa which are rare but not sensitive could be excluded. However, this approach requires further research.

In general, the results of MarBIT correspond to those results shown by Nehls and Büttger (2006) and Büttger *et al.,* 2008: species composition of the associated macrobenthic community of mussel beds is almost stable and did not show pronounced changes. So far, structural changes of mussel beds do not affect macrobenthic composition of mussel beds.

The MarBIT-index is most sensitive to changing abundances of "normal" taxa and it is insensitive to changing abundances of rare or abundant taxa. Perhaps this parameter is less suitable in the Wadden Sea because of its naturally high fluctuations of abundances. Leaving it aside might be possible. But the parameter 'abundance' is a demand of

Table 2: Evaluation of the macrobenthic community of blue mussel beds in the tidal basins Lister Deep (LT) and Norderhever (NH) between 1999 and 2005 with the MarBIT-tool.

	including neozoa	without neozoa
Apool-LT-1999	0,610 (good)	0,638 (good)
Apool-LT-2000	0,719 (good)	0,751 (good)
Apool-LT-2001	0,735 (good)	0,721 (good)
Apool-LT-2002	0,645 (good)	0,655 (good)
Apool-LT-2003	0,742 (good)	0,733 (good)
Apool-LT-2004	0,575 (moderate)	0,583 (moderate)
Apool-LT-2005	0,661 (good)	0,667 (good)
Apool-NH-1999	0,534 (moderate)	0,606 (good)
Apool-NH-2000	0,577 (moderate)	0,655 (good)
Apool-NH-2001	0,589 (moderate)	0,629 (good)
Apool-NH-2002	0,565 (moderate)	0,585 (moderate)
Apool-NH-2003	0,618 (good)	0,646 (good)
Apool-NH-2004	0,438 (moderate)	0,347 (poor)
Apool-NH-2005	0,618 (good)	0,568 (moderate)

the WFD. Furthermore, increasing abundances of species which are not on the reference list will not affect the evaluation.

The MarBIT-tool does not include biomass changes so far. Generally, biomass is an important parameter in the North Sea (see summary given by Westerhagen and Dethlefsen, 2003; Kröncke *et al.,* 1998, 2001) as well as in the Wadden Sea. Including this parameter might be worthwhile. But the questions would be how to define a reference for it and what variations would be acceptable.

6. Open questions and recommendations

It is unclear how to deal with alien species in the evaluation and the discussion is still in progress. Schories and Selig (2006) recommend including alien species in evaluations but they should lead to down-weighting. On the other hand, most alien species are tolerant and euryoecious species so that their absence indicates unfavourable ecological conditions (Meyer *et al.,* 2007). Most aliens cannot be removed from the Wadden Sea. If aliens lead to down-weighing, EQRs could never become 'good' or 'high' as long as aliens occur. But removal will not be feasible for most species (Meyer *et al.*, 2007).

Pacific oysters exhibit a special situation in the Wadden Sea. In many areas, oysters are dominating former blue mussel beds and becoming the new habitat engineers (Nehls and Büttger, 2007). As far as the MarBIT tool shows, the evaluation is not significantly different to those times when sites were mussel beds. This aspect fits with other observations that showed that oyster beds inhabit a similar community composition as blue mussel beds but changes became obvious in dominance structures and in increasing diversity (Kochmann, 2007; Büttger *et al.,* 2008; Markert *et al.,* 2009). As mussel beds have declined for several years, oyster beds have fulfilled a similar function: they serve as habitat for many endobenthic and epibenthic species, they offer food and protection. Although, some species like common Eiders do not derive the same benefits from oyster beds as from blue mussel beds (Scheiffarth *et al.,* 2008). The spread of the oysters is a comparatively recent process and its effects on the associated communities and the food web are not yet completely known.

In order to evaluate the ecological status of the Wadden Sea based on mussel beds, we recommend enhancing the MarBIT-tool with evaluations of further parameters like spatial distribution and size of mussel beds. A combined evaluation leads to a more reliable result reflecting different aspects of this unique habitat in the Wadden Sea. It would be meaningful to test this first approach with data from Lower Saxony, Denmark or The Netherlands for improvement.

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Trends in numbers and distribution of breeding birds in the Wadden Sea

Kees Koffijberg & Lieuwe Dijksen, SOVON Vogelonderzoek Nederland, Beek-Ubbergen, kees.koffijberg@sovon.nl, Bernd Hälterlein & Stefan Schrader, Nationalparkverwaltung im Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Karsten Laursen, Danmarks Miljøundersøgelser (NERI) & Aarhus University, Petra Potel, Nationalparkverwaltung Niedersächsisches Wattenmeer

1. Introduction

For several breeding bird species like Eurasian spoonbill *Platalea leucorodia*, oystercatcher *Haematopus ostralegus*, avocet *Recurvirostra avosetta*, Kentish plover *Charadrius alexandrinus*, common redshank *Tringa totanus*, lesser black-backed gull *Larus fuscus*, gull-billed tern *Gelochelidon nilotica* and sandwich tern *Sterna sandvicensis*, the Wadden Sea is among the most important breeding sites in Northwest-Europe. Several species are listed in Annex I of the EU Birds Directive, have the status as Species of European Concern (SPEC) and/or represent national Red List species. Monitoring of breeding birds in the Wadden Sea has been carried out since 1991 by the Joint Monitoring Group for Breeding Birds (JMBB) in the framework of the Trilateral Monitoring and Assessment Program (TMAP) (Fleet *et al.*, 1991; Melter *et al.*, 1997; Rasmussen *et al.*, 2000; Koffijberg *et al.*, 2006). The monitoring scheme focuses on 31 target species that are considered characteristic for the Wadden Sea ecosystem. Common breeding birds (eight species) are counted annually in 103 representative census areas evenly distributed over all regions and habitats. Colonial and rare breeding birds (23 species) are difficult to survey with sample areas and are counted by annual complete counts. Once every five years a total count of all target species is carried out (1991, 1996, 2001, 2006, interval now changed to once every six years).

The monitoring scheme principally aims to assess and detect population size, distribution and population trends, while taking into account other factors such as management issues and climate change. Fieldwork is standardised and carried out according to trilaterally harmonised methods. Nearly 500 ornithologists participate in the counts, mainly staff of NGOs, governmental bodies, site managers and volunteers. A Quality Assurance Meeting (QAM) is organised regularly to provide a platform for exchange of field experience among counters and discussion of specific counting pitfalls (Blew, 2003). This contribution presents an overview of the most important results, based on the next trilateral breeding bird report that will be published 2009-2010.

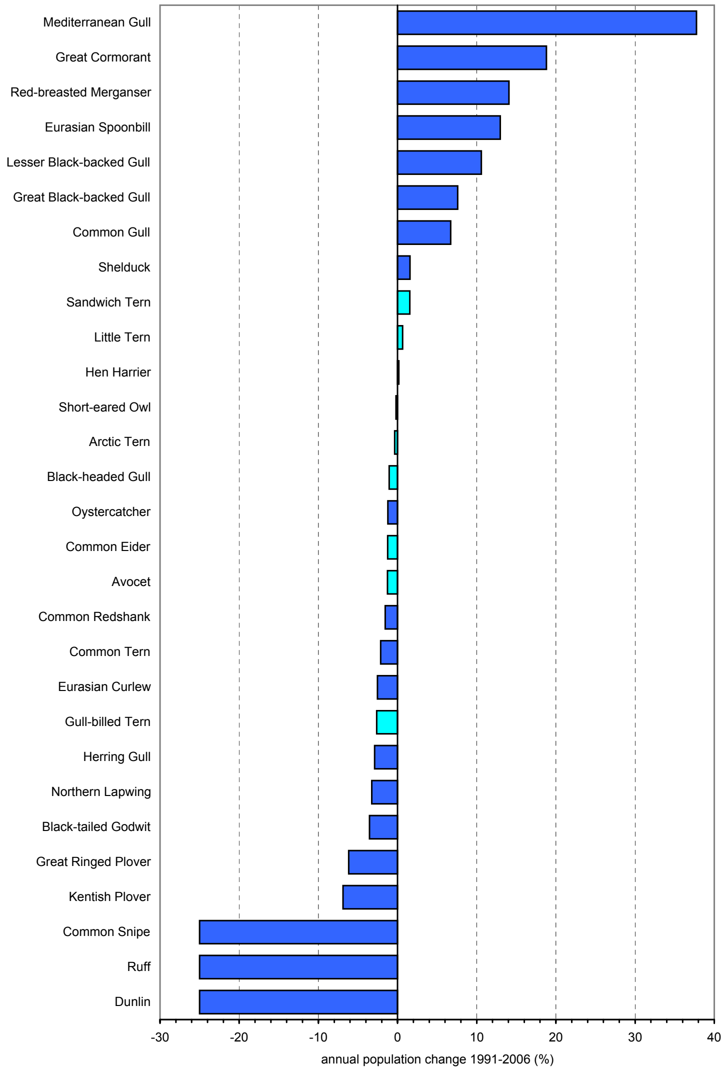
2. Results

2.1 Trends in breeding birds 1991-2006

Reliable trend estimates, assessed with the commonly used TRIM package from Statistics Netherlands, are available for 29 species. Over the period 1991-2006 nearly half of the monitored species (13) have been subject to declines. Furthermore, eight species have increased whereas for seven species the breeding population remained stable over the years. Gull-billed tern, for which the Wadden Sea represents the single breeding site in Northwest-Europe, is the only species for which no significant trend could be detected (numbers fluctuate from year to year).

With 11 out of 13 declining species, strongest declines have been observed in waders (Figure 1). Dunlin *Calidris alpina schinzii*, ruff *Philomachus pugnax* and common snipe *Gallinago gallinago* balance on the verge of extinction and might well disappear before the next total count in 2012. All three species have also declined in other parts of the breeding range (Zöckler, 2002; Thorup, 2006). Their Wadden Sea breeding sites are only maintained by specific conservation measures (Thorup, 2003), including a more bird-friendly management of coastal grassland behind the seawall. The sites are mainly in Denmark, within the trilateral cooperation area in that country and are of prime importance for wader populations occurring in the Wadden Sea. Of the regularly breeding wader species, Kentish plover and great ringed plover *Charadrius hiaticula* show the highest rate of decline and both have abandoned many breeding sites in the past decade. Both species are known to suffer from disturbance by beach recreation (Schulz, 1998; Tulp, 1998). In addition,

Figure 1:
Trends in breeding birds 1991-2006, expressed as the rate of annual population change (in %). Non-significant changes are marked light-blue. Population changes in common snipe, ruff and dunlin are estimated from the data of the total counts 1991, 1996, 2001 and 2006.



many temporarily used breeding sites (embankments, industrial areas) have been abandoned as vegetation succession made habitat unsuitable to breed (Hälterlein, 1998), whereas natural coastal dynamics – a prerequisite to maintain suitable breeding habitat – is lacking at most sites. Conservation measures (*i.e.* prevention of disturbance at breeding sites) have been carried out in several parts of the Wadden Sea, but have not been successful so far in halting a further overall decline. Only in Denmark is Kentish plover is still thriving, and further investigations (also in the framework of the new TMAP parameter 'breeding success') hopefully will provide some clues as to what measures could improve the situation in both species. Furthermore, ecological restoration measures, as e.g. proposed by the 'Het Tij Geleerd' program in The Netherlands, might be able to restore some of the former coastal dynamics and provide new breeding opportunities.

Largest increases have been observed in a number of colonial breeding birds, notably Mediterranean gull *Larus melanocephalus*, great cormorant *Phalacrocorax carbo sinensis*, Eurasian spoonbill, lesser black-backed gull and common gull *Larus canus*. In particular, Mediterranean gull and Eurasian spoonbill have expanded their breeding range from southwest to northeast and are now breeding in most parts of the Wadden Sea. In the next years, these species will probably expand their breeding range further north. Great cormorant has shown signs of stabilisation in most inland colonies in Europe (Bregnballe *et al.*, 2003) but it still explores new breeding and feeding sites in the Wadden Sea. Only settlement in Denmark has been halted so far, as nests and eggs are controlled annually to prevent successful breeding (Bregnballe and Eskildsen, 2009). Elsewhere, safe breeding sites (mainly islands) might become a limiting factor, resulting in a saturation of the current population level.

For many species, the trends in 1991-2006 are consistent throughout the whole 16-year period. However, changes in indices between 2001-2006 suggest that some formerly thriving species or species with a long-term stable trend have tended to decline recently. This especially applies to common eider, arctic tern *Sterna paradisaea* and little tern *Sterna albifrons*. All three species have shown nearly annual declines since 2001, and meanwhile have suffered losses of 20-40% of the population in 2001. In common eider, downward trends have been reported already for a longer term in the important breeding areas in The Netherlands, due to limited sublittoral mussel stocks that were depleted by fisheries (see below). On the other hand rates of decline in oystercatcher and avocet were lower from 2001 onwards, indicating that the long-term overall negative trends in these species seems to be levelling off. Increases in common gull and lesser black-backed gull have levelled off as well, suggesting saturation of the existing colonies and perhaps density-dependent factors starting to operate.

2.2 Regional differences

Given the large geographical range and differences in management, it is not surprising that many species do not show comparable trends within the four sections of the Wadden Sea (Figure 2). Regional differences in trends are important in several aspects. They might provide a first clue about the mechanisms that have caused bird populations to decline, especially when also comparing breeding success in the next years (after implementation of this parameter in TMAP has been completed in 2010). West of the River Elbe, generally more species breed in higher numbers, but among them there are also more declining species than north of the River Elbe. When regarding the 16 species that breed all over the Wadden Sea, it is obvious that most populations breeding in the Danish Wadden Sea are generally thriving. The large number of fluctuating trends in this section of the Wadden Sea is probably a result of the small size of the Danish part of the Wadden Sea (and thus smaller breeding populations). In the other three sections of the Wadden Sea different developments are more or less balanced. The Netherlands have slightly more species (seven) going down more than Niedersachsen and Schleswig-Holstein (both six species).

Remarkable differences in regional trends are especially found in oystercatcher (increase in Niedersachsen, declining or stable numbers elsewhere), great ringed plover (stable in The Netherlands, declining elsewhere) and Kentish plover (increase in Denmark, declining elsewhere). All three species are declining on the scale of the entire Wadden Sea. Furthermore a south-north gradient appears in population trends of shelduck (increasing to stable towards the north), avocet (declining to increasing, apart from small fluctuating population in Denmark) and herring gull (declining to increasing). In most other species no specific pattern in regional trends can be detected.

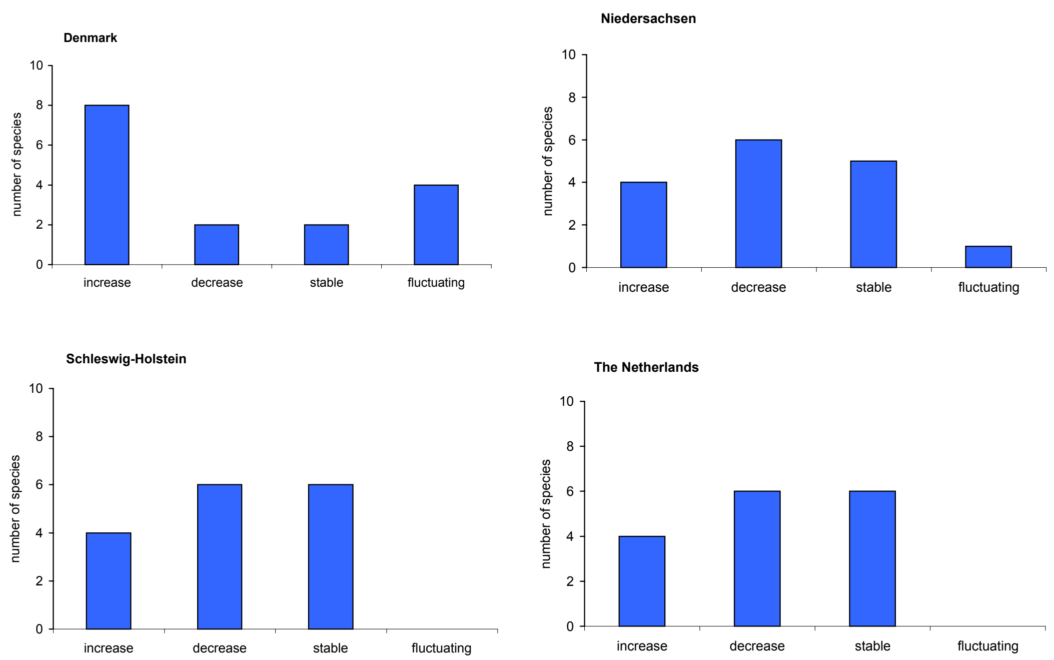


Figure 2: Summary of regional trends 1991-2006. Given is the number of species in each trend category for the four respective Wadden Sea countries. 'Fluctuating' represents non-significant trends. Only species that occur in relevant numbers in all four countries have been included (N = 16).

3. Target evaluation

The current Wadden Sea Plan (1997) puts forward two targets that are considered relevant for breeding birds: (1) favourable food availability and (2) natural breeding success.

3.1. Favourable food availability

With regard to limited food stocks, shellfish-eating birds received particular attention in the past decade. For oystercatcher and herring gull *Larus argentatus*, downward trends in breeding birds coincide with negative trends observed in migratory birds (that are part of the same population as dealt with in the breeding birds' scheme). Migratory and wintering common eider *Somateria mollissima* have been subject to declines as well, although only breeding bird numbers in The Netherlands (*i.e.* the core breeding area within the Wadden Sea) have gone down significantly so far. All three species have suffered from the limited stocks of sublittoral blue mussels *Mytilus edulis* in the Dutch Wadden Sea that were depleted mainly by shellfish fisheries in the beginning of the 1990s (Desholm *et al.*, 2002; Rappoldt *et al.*, 2003; Ens *et al.*, 2004; Leopold *et al.* 2004; Verhulst *et al.*, 2004; Kats 2007). In the eastern part of the Dutch Wadden Sea partial recovery of mussel beds has been observed, but an overall population recovery in shell-fish eating birds has not been observed so far. For oystercatcher, Van de Pol *et al.* (2007) have also shown that the chance of flooding events (due to more stormy weather) in the breeding season has increased and has had a negative impact on breeding performance. This clearly demonstrates the possible impact of changing weather patterns as part of global climate change. In herring gull, the general abandonment of open rubbish dumps will also have contributed to the negative trend (Koffijberg *et al.*, 2006).

Apart from the rather well-investigated shellfish-eating birds, the role of available food stocks in other species groups is largely unknown and sometimes contradictory. Long term upward trends in *e.g.* ragworm *Nereis diversicolor* densities, in the Dutch Wadden Sea perhaps enhanced by (now prohibited) mechanical cockle dredging (Leopold *et al.*, 2004), would be beneficial to species like avocet. However, avocet is showing downward trends west of the River Elbe. At least for some sites in Niedersachsen and the eastern Wadden Sea in The Netherlands, this is associated with low reproduction rates due to high predation risk, mainly of red fox *Vulpes vulpes* (Willems *et al.*, 2005, de Boer *et al.*, 2007; Melter and Vaas, 2008). Predation is also know to play a role in common redshank (Thyen *et al.*, 2005), black-headed gull (Oltmanns, 2003; Koffijberg *et al.*, 2006) and common tern *Sterna hirundo* (Dijksen and Koks 2003). However, its impact on Wadden Sea scale is not clear as breeding success has not been monitored yet and specific studies to quantify predation rates in the Wadden Sea are scant. Species breeding on the mainland coast are especially susceptible to predation, as usually important mammalian predators like red fox or mustelids are absent on the islands. This probably also explains that species like avocet and black-headed gull are generally doing better on island-breeding sites (trend 1991-2006: stable) than along the mainland coast (trend 1991-2006: decline). On the other hand, trends in common tern are diametrically opposite what would be expected from predation risk: populations on the mainland coast are performing better than those on islands. In this species, food availability might be a better explanation for the observed trends (Brenninkmeijer *et al.* 1997; Stienen *et al.*, 2009; *cf.* recent declines in arctic tern and little tern), but again, this aspect has not been investigated in detail as the monitoring scheme does not include research to unravel backgrounds for the observed trends. Breeding on the fringe of land and water, terns are also susceptible to flooding events during the breeding season, as has been demonstrated frequently for breeding sites like the island of Griend in the Dutch Wadden Sea (Stienen *et al.*, 2009; *cf.* oystercatcher mentioned previously).

3.2 Breeding success

Breeding success is an important parameter that has not been monitored trilaterally so far. Hence, a proper evaluation regarding the target natural breeding success is not possible yet. The pilot project 1996-97 (Exo *et al.*, 1996; Thyen *et al.*, 1998) showed the importance of this parameter and previous Quality Status Reports have recommended that monitoring of breeding success should be started (de Jong *et al.*, 1999; Essink et al,. 2005). Therefore, it is a major step that it was decided recently to include monitoring of breeding success as a parameter in TMAP. It will be fully implemented in the breeding season of 2010, but some fieldwork was already started in 2009. In The Netherlands, a monitoring scheme for breeding success has been carried out since 2005, initially as part of an investigation on shellfish-eating birds (Willems *et al.*, 2005) and now in the framework of a governmental monitoring and research project (de Boer *et al.* 2007). For three of the six species surveyed in The Netherlands (oystercatcher, avocet and herring gull), it was

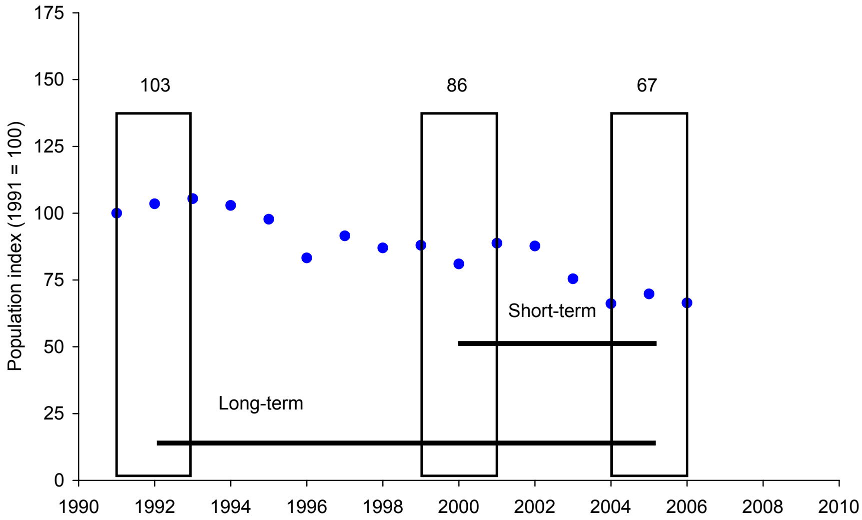


Figure 3: Example of possible application of alerts in Wadden Sea breeding birds. Annual indices for herring gull are shown for 1991-2006. Average indices for three-year time windows have been calculated to point at short- and long term trends. When population declines exceed 25% a medium alert is flagged, when 50% declines are observed a high alert is flagged. In this case, the overall trend in herring gull is negative, but only for the long-term (-35%) a medium alert is flagged; at short term (-22%) no alert is flagged.

shown that downward trends observed in these species in the Dutch Wadden Sea are indeed triggered by a poor breeding performance. Extension of monitoring of breeding success to other parts of the Wadden Sea would enable much more insight into the mechanisms that cause changes in breeding bird populations and help to understand regional differences in the patterns observed and their possible links to management issues or other TMAP parameters like contaminants in bird eggs (Becker and Muñoz-Fuentes, 2004).

4. New ways to communicate trend data: the application of alerts

So far, presentation of trend data has been rather straightforward, using simple symbols to indicate declining, stable, increasing and fluctuating populations. This approach requires some general knowledge on population dynamics in breeding birds. Moreover it is sensitive to annual variation in numbers as it does not take into account the species' biology. In the United Kingdom, so-called alert-limits have been established to indicate trends in bird numbers and initiate conservation action that has to be taken when alerts are flagged (Atkinson *et al.*, 2006). Alerts are pre-defined trend classifications that express population changes within certain time-windows (*e.g.* 5, 10 or 25 years). When declines exceed certain threshold values (e.g. 25 or 50%), an alert is flagged. Alerts are flagged for short- and long-term changes. Moreover, biological filters can be applied to consider a species' biology (e.g. short- versus long-lived). Currently, an application of alerts is in preparation for the Wadden Sea (Blew & Koffijberg *in prep.*). For breeding birds, average indices of three-year periods will be used to assess population changes in a five- (short-term), ten- (medium term) or 16 year-period (long-term). Several details still have to be decided (e.g. exact time-windows to use, what biological filters to apply, etc.), but an example of alerts is given in Figure 3. Alerts can also easily be used to point at regional differences in trends. Implementation is foreseen for 2010-2011. They will be part of the regular trend updates that are in preparation for the TMAP website (www.waddensea-secretariat.org)

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Assessing the status of Wadden Sea fish

Jager, Z. info@ziltwater.eu, L.J. Bolle, A. Dänhardt, B. Diederichs, G. Lüerßen, H. Marencic, T. Neudecker, J. Scholle, R. Vorberg

Abstract

Although the Wadden Sea is considered as a coastal water under the Water Framework Directive (WFD), which does not consider fish as a biological quality element, the TMAP ad hoc fish group was inspired by the approach that was chosen for the development of a fish index for the implementation of the (WFD) in transitional waters. The WFD fish index combines and assesses a number of metrics: selected variables of the fish community that together are considered to give a good reflection of the status of the fish (species composition and abundance) in the specific water body. The present state is compared to 'undisturbed' conditions, while the underlying assumption is that the metrics are in some way related to anthropogenic pressures on the water system.

The feasibility of this approach for the Wadden Sea fish fauna was evaluated. The lack of (quantitative) historic data makes it impossible to describe, or compare to, a pristine situation which can be used to define targets. The complexity of the Wadden Sea ecosystem and the lack of fundamental scientific knowledge make it extremely difficult to identify driving forces behind the observed changes in the fish fauna. Changes in the Wadden Sea fish fauna (where "more" is not necessarily "better") can be caused by human pressures, but also by natural variability. They can be a result of local processes (occurring within the Wadden Sea) or of large scale processes (occurring in the connected marine or freshwater systems). Furthermore, it is difficult to disentangle direct effects and indirect effects caused by inter-specific interactions.

Nevertheless, the TMAP fish group tried to develop targets and an assessment tool for trilateral Wadden Sea fish. First, a basic reference list was compiled describing the fish species that (can) occur in the Wadden Sea. To help select priority fish species, different selection criteria were considered. These were grouped into criteria on ecology, relevance for management, and sensitivity to driving forces. In addition, monitoring aspects counted as well. A selection of 14 priority species, scoring high on both types of selection criteria as well as monitoring results, was further considered in a joint data analysis of the Demersal Fish Survey (DFS; Wageningen IMARES, The Netherlands), the Demersal Young Fish Survey (DYFS; von Thünen Institut, Germany) and the Schleswig-Holstein Survey (SHS; National Park Agency and Marine Science Service, Germany).

The analyses were carried out on the level of QSR subregions, inside the Wadden Sea proper, thus providing a high spatial resolution. Trends in species richness, species composition and mean abundance of priority species since 1970 were determined, thus providing a good temporal coverage. The observed values are compared to the long term average, to identify relevant changes in indicator species and metrics and relate those, if possible, to causal factors. The (im)possibility of defining targets for Wadden Sea fish is illustrated by the results of this joint analysis.

1. Introduction

The shallow coastal waters of the Wadden Sea and its tributary estuaries support reproduction, maturing and feeding of fish and they serve as an acclimation area and transit route for long-distance migrants from sea to their spawning grounds located in fresh water (*e.g.* Haedrich, 1982; Kerstan, 1991; Elliott and Dewailly, 1995; Elliott and Hemingway, 2002; Elliott *et al.*, 2007). The estuaries, with their pronounced salinity gradient due to the mixing of riverine and marine waters, constitute a habitat of a very particular nature within the Wadden Sea. The Wadden Sea ecosystem is also connected with and influenced by the North Sea: marine juvenile and marine seasonal species form an important constituent of the Wadden Sea fish fauna.

Intermingled with the anthropogenic pressures (Lozán *et al.*, 1994; Schuchardt *et al.*, 1999; 2007; Essink *et al.*, 2005), natural variability plays a very important role. These pressures are reflected in the aquatic biotic communities and in the fish fauna in particular. Recently, an increasing number of publications point to the relationship between the North Atlantic Oscillation (NAO) and fish populations (Attrill and Power 2002, Henderson and Seaby 2005) or the effects of increasing water temperatures on fish (Henderson and Seaby 1994, Genner *et al.*, 2003, Pörtner and Knust 2007, Van Keeken *et al.*, 2007).

Despite the recognised importance of fish as an element of the Wadden Sea ecosystem (Vorberg *et al.*, 2005), fish was not considered in the Trilateral

Wadden Sea Plan (1997). In the mean time, the need to include fish in the Wadden Sea Plan and the TMAP has grown because the Water Framework Directive (WFD, 2000/60/EC) recognizes fish as a biological quality element for transitional waters (estuaries) and selected fish species are listed in the Habitats Directive (HD, 92/43/EEC). In addition, characteristic fish species should be used to assess the status of the relevant habitat types described in the HD (e.g. H1110 submerged sandbanks[1], H1130 estuaries, H1140 sand- and mudflats). Furthermore, some fish species serve as main food item for birds or seals that are listed under the Bird and Habitats Directive for the Wadden Sea. Recently, the Marine Strategy Framework Directive (2008/56/EC) has been adopted and is now being implemented. In this Directive, fish again are one of the qualitative descriptors of good environmental status.

Because the TMAP common package (TMAG, 1997) does not include fish monitoring, one is dependent on information that is provided by fish monitoring for other purposes (fish stock assessment for ICES) or (European) obligations. Following the requirements of the EU Water Framework Directive, new fish monitoring was initiated in 2006 in all Wadden Sea estuaries (the 'transitional waters' of the Ems, Weser, Elbe and Eider). In contrast to transitional waters, fish is not considered as a WFD biological quality element for coastal waters such as the Wadden Sea.

Proposed Fish targets for the Wadden Sea

As one of its tasks in supporting the TMAP revision process, the TMAP ad hoc fish expert group (established March 2006) formulated (preliminary) trilateral targets for fish as follows:

- Presence of a typical Wadden Sea fish fauna
- Occurrence and abundance of fish species according to the natural dynamics in (a)biotic conditions

In addition to these general targets of a typical Wadden Sea fish fauna, conditional sub-targets can be formulated for the different ecological guilds:

- Unhindered migration between the sea and upstream and/or inland waters [for diadromous fish],
- Viable stocks [populations] and a natural reproduction of typical fish species
- Diversity of habitats (subtidal areas and tidal flats, including areas with seagrass and mussel beds), to provide shelter and food for juvenile fish [nursery function] and substratum for spawning [for estuarine resident species and marine seasonal species]
- Suitable physical, chemical and morphological conditions with the underlying dynamic processes typical for tidal areas [for resident species and marine seasonal species].

Beside the fish targets and sub-targets, the topic of trophic integrity should be addressed in the Wadden Sea Plan Targets. Fish is an important food resource for birds and marine mammals. To sustain populations of the latter the following target is proposed:

- A natural fish fauna, providing food for sustainable populations of fish-eating birds and marine mammals.

To Denmark, the houting (*Coregonus oxyrinchus*) is a very important target species.

2. Methods

2.1 Overview of fish monitoring data available to TMAP

An overview of ongoing long-term fish monitoring programs of the different countries in the trilateral Wadden Sea area was reported (TMAP 2006). The most extensive and long-running are the Demersal Fish Survey (DFS, Wageningen IMARES) and the Demersal Young Fish and Brown Shrimp Survey (DYFS, von Thünen Institut). The survey methods are described in Boddeke *et al.,* (1970), Boddeke *et al.* (19729, Neudecker (2001) and ICES (2006a). Pelagic monitoring with a stow net has been carried out in the Schleswig-Holstein Wadden Sea (Schleswig-Holstein Stow net survey (SHS), National Park Agency and Marine Science Service) since 1991 (Meldorf Bight) or 2001 (Hörnum Deep) (Vorberg, 2001). The Seabird-Fish interaction survey is not a regular monitoring program but was undertaken for specific research goals (Dänhardt and Becker, 2008). The results of the NIOZ fyke net monitoring (since 1960 in the western Wadden Sea) were not available for analysis; results have been published in Van der Meer *et al.* (1995) and Philippart *et al.* (1996). The WFD monitoring data were not suitable for trend analyses, because this monitoring was only initiated in 2006.

2.1 Towards a Fish assessment tool

To assess the status of fish in the Wadden Sea, a joint data analysis was carried out, based on the

1 For H1110A in the Netherlands, recently the following fish species have been listed as qualitative indicators (LNV Profieldocument H1110, version of September 2008): *Clupea harengus*, *Liparis liparis*, *Myoxocephalus scorpius*, *Pholis gunnellus*, *Platichthys flesus*, *Pleuronectes platessa*, *Pomatoschistus minutus*, *Syngnathus acus*, *Zoarces viviparus*.

Species	Name	Ecological guild	Stratification
Alosa fallax	Twaite shad	CA	Pelagic
Osmerus eperlanus	Smelt	CA	Pelagic
Lampetra fluviatilis	River lamprey	CA	Pelagic
Platichthys flesus	Flounder	ER	Demersal
Zoarces viviparus	Eelpout	ER	Demersal
Ammodytes sp.	Sand eel	ER	Pelagic and Buried
Pleuronectes platessa	Plaice	MJ	Demersal
Solea solea	Sole	MJ	Demersal
Limanda limanda	Dab	MJ	Demersal
Gadus morhua	Cod	MJ	Demersal
Merlangius merlangus	Whiting	MJ	Demersal
Clupea harengus	Herring	MJ	Pelagic
Sprattus sprattus	Sprat	MS	Pelagic
Engraulis encrasicolus	Anchovy	MS	Pelagic

Table 1: Priority species to be included in the spatial and temporal trend analyses, ordered by ecological guild (CA=diadromous, ER=estuarine resident, MJ=marine juvenile, MS=marine seasonal). After Bolle *et al.*, 2007.

WFD-approach. For a better understanding, the WFD assessment procedure is described briefly. The developed WFD estuarine fish index combines a number of fish metrics which together give a good reflection of the status of the fish in the specific water body; the underlying assumption is that the metrics are in some way related to anthropogenic pressures acting on the water system (details in Jager and Kranenbarg 2004, Bioconsult 2006a, 2007a, Scholle *et al., in prep.*, Scholle and Schuchardt *in prep.*, Kranenbarg and Jager 2008). The WFD fish metrics for transitional water bodies (estuaries) consist of species composition indices, based on the number of species in certain ecological guilds, and abundance indices of key species. These are compared with a reference situation. The assessment tool aggregates the metrics scores of the index to calculate the status of the water body, based on the available monitoring data.

2.2 Reference list of Wadden Sea fish species

As a starting point for the development and evaluation of trilateral targets for Wadden Sea fish, a basic reference list was compiled describing the fish species that (can) occur in the Wadden Sea (Annex I). Information was derived from the running monitoring programs, such as the >35-year data sets of the demersal (young) fish survey in The Netherlands and Germany and of the stow net surveys in Schleswig-Holstein, Lower Saxony and from the River Elbe. In addition, species lists from the literature were used (Witte and Zijlstra, 1979; Fricke *et al.*,, 1994; Vorberg and Breckling, 1999). Altogether the list spans several decades.

2.3 Selection of Priority Species

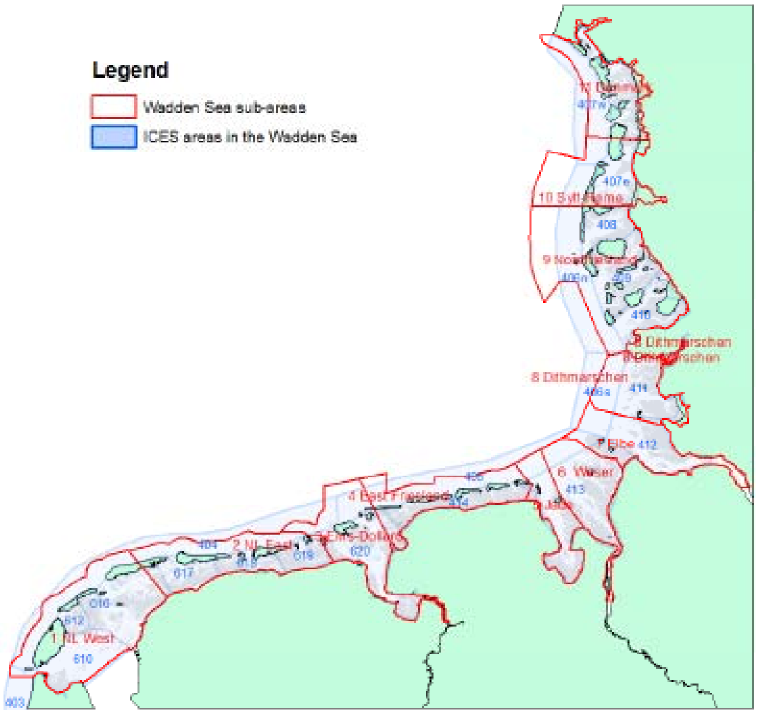
The objectives of (TMAP) fish monitoring are to assess the status and the development of relevant or characteristic fish species in the Wadden Sea. In practice it is impossible to do this for all the fish species potentially occurring in this area. To help select the priority fish species, various selection criteria were applied (TMAP, 2006). They were grouped into criteria on ecology (ecological guild, habitat preference), relevance for management (HD-species or species belonging to the characteristic fish fauna of HD habitat types, WFD-species, endangered or vulnerable species, food for birds or marine mammals) and sensitivity to driving forces (climate change, nutrient enrichment, habitat degradation, fishing mortality and local pressures). In addition, monitoring criteria were considered (abundance, occurrence and catchability in the ongoing monitoring programs). Applying these criteria resulted in an exhaustive table, indicating the scores of different fish species according to the criteria mentioned above. A selection of 14 'priority species', scoring high on these selection criteria (Table 1), was further considered in a joint data analysis (Bolle *et al.*, 2007, 2009).

The allis shad (*Alosa alosa*), sea lamprey (*Petromyzon marinus*), houting (*Coregonus oxyrinchus*) and ruffe (*Gymnocephalus cernuus*) scored high on ecological and management relevance but are not covered by the current monitoring methods and programs. Despite their relevance, they could not be taken further into the analyses.

2.4 Joint analysis of survey data

A joint analysis of the German DYFS and the Dutch DFS was made possible because the methods had previously been harmonized in the ICES working group on beam trawl surveys (see for example ICES, 2006a). The demersal survey data have been analysed by QSR sub-area (Figure 1), which allows comparison of trends in abundance of species between different parts of the trilateral

Figure 1: Map of the Wadden Sea sub-areas or QSR areas (as defined within the context of Quality Status Report), and the ICES areas or D(Y)FS areas (as defined in the original DFS/DYFS survey design). 1. Western Dutch Wadden Sea, 2. Eastern Dutch Wadden Sea, 3. Ems-Dollard, 4. East Frisia, 5. Jade, 6. Weser, 7. Elbe, 8. Dithmarschen, 9. North Frisia, 10. Sylt-Rømø, 11. Denmark. Areas 5, 6, 10 and 11 were excluded from (part of) the joint analyses due to insufficient data.



Wadden Sea. In addition, the SHS was involved in the joint analysis as far as the data allowed it. Full descriptions of the methodology and the outcome of the joint analysis are presented in Bolle *et al.* (2009), whereas selected results are presented in the Wadden Sea Quality Status Report 2009.

2.5 Selection of fish metrics in the joint analysis

The TMAP ad hoc fish expert group evaluated whether the WFD fish index could also be implemented for the entire Wadden Sea, taking into account differences in fish populations and environmental pressures as well as the difficulty in defining reference conditions for the entire Wadden Sea area.

The following fish metrics were included in the Wadden Sea analyses (Bolle *et al.*, 2009):

Species richness

Species richness was defined as the total number of species observed in a region in a year. In principle all fish were scored at the species level, but due to identification problems a higher taxonomic level was chosen for some groups of species (Bolle *et al.*, 2009).

Species composition

Species composition was defined as the total number of species per ecological guild, calculated for each year and region. The ecological guilds considered most relevant for the Wadden Sea are: CA (diadromous), MJ (marine juvenile) and ER (estuarine resident) (Elliott and Hemingway 2002). The term ER indicates the species that spend the majority of their lifespan in the Wadden Sea; whether or not the species also occurs (abundantly) outside the Wadden Sea is irrelevant. The other categories (excluding freshwater species) were combined in one group.

Mean abundance

The catch rates per haul were standardized to numbers per 1000 m^2 (D(Y)FS beam trawl) or to numbers per 1,000,000 m^3 (SHS stow net). These abundance estimates were then averaged by year and region. For the beam trawl surveys, a weighted mean was calculated in which the abundance estimates were weighed by the surface area of the depth strata (for further details see Bolle *et al.*, 2009).

Trends in abundance

For the DFS and DYFS, trends in mean abundance were analysed using TrendSpotter, which is an analytical method based on structural time-series models in combination with a Kalman filter (Visser, 2004). Full details of this analysis are described in Bolle *et al.* (2009). TrendSpotter was used to model the trend between 1970/1974 - 2006 and to assess the significance of a positive or negative trend.

Mean length

Length (mean, median, maximum) is commonly used as an indicator in marine ecosystems (see literature review in Appendix 4 of Bolle *et al.*, 2007). A shift in mean length indicates a change in the (sub-)population structure. The mean length was calculated as the $\Sigma(N^*length)/\Sigma N$, in which N is number of fish; for further details see Bolle *et al.* (2009).

3. Results

3.1 Fish species in the Wadden Sea

The Wadden Sea fish fauna consists of 150 species, including 13 freshwater species (Annex 1). Of the 150 Wadden Sea species, 50 (33,6%) are common, 26 (17,3%) are fairly common, but 74 (49,7%) have to be considered as rare or even extremely rare in the Wadden Sea. Of the 76 (fairly) common Wadden Sea fish species, 9 were diadromous, 15 estuarine resident, 12 marine juvenile, 9 marine seasonal and 28 marine adventitious, plus 3 fresh water species (*cf.* Elliott and Hemingway, 2002). New species in the Wadden Sea are the black goby *Gobius niger* (H. Asmus, pers. comm.) and the exotic Atlantic croaker *Micropogonias undulatus* which turned up in the Weser in 2004 (Bioconsult, unpubl.).

3.2 Species richness and species composition

A major drawback of the parameter 'species richness' is its dependence on the number of hauls. Figure 2 clearly illustrates that the number of species encountered in the Dutch DFS increases with the number of hauls (per year and region). In principle, the number of species will increase asymptotically with the number of samples. This relationship (partly) explains the differences in species richness between western and eastern Dutch Wadden Sea and Ems-Dollard.

The species richness as determined by the analysis of the DFS and DYFS ranged between 11 and 33 species per year over the period (October) 1970-2007 (Figure 3). Overall there appears to be no clear temporal trend, neither in species richness, nor in species composition in terms of ecological guilds. The number of estuarine resident species is remarkably stable, especially in the western and eastern Dutch Wadden Sea. Not much variation is observed in the number of marine juvenile species either. Most of the variation in species richness is caused by the number of diadromous species or marine seasonal/ marine adventitious species. The number of species in the SHS survey ranged between 18-29 (Meldorf Bight 1991-2008, sub-area 8 - Dithmarschen) or 22-27 (Hörnum Deep 2001-2008, sub-area 9 - North Frisia) (Figure 4.).

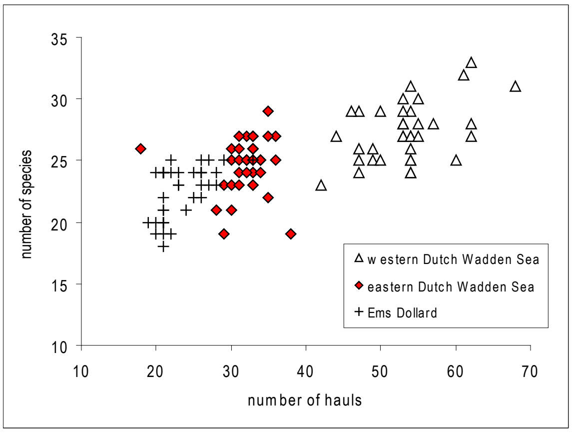


Figure 2: Number of species per year and region in relation to the no. of hauls per year and region (Bolle *et al.*, 2009).

3.3 Trends in abundance of selected Wadden Sea fish species ("priority species")

The selected results of the beam trawl surveys (DFS, DYFS) presented here are based on the joint analysis that is described and reported in full detail in Bolle *et al.* (2009).

The trends in abundance of 'priority species' are summarised in Table 2 (like Table 1 ordered by ecological guild). The observed trends differ between species and regions. Overall, more downward than upward trends are observed. A pattern that emerges in several species and regions is an increase in abundance in the 1970s, followed by a decrease during the 1980s or 1990s. During the period covered, an overall increase was shown in the smelt, flounder, herring and sprat. An overall decrease was found in eelpout, plaice, sole, dab, cod and whiting. No significant trends were observed in twaite shad and sandeel. Sometimes the trends were only significant during a few years, or more pronounced in one sub-area or period than in another (Table 2).

3.4 Mean length of fish in the Wadden Sea

The mean length of the plaice population in the western Wadden Sea decreased from approximately 13 cm during the 1970s to about 9 cm in the last decade. The mean length of sole, in contrast, did not show a significant trend, but fluctuated around a long-term average of 10 cm (Figure 5; Bolle *et al.*, 2009). Nevertheless, the abundance of sole in the Wadden Sea decreased significantly, but this apparently involved all length-classes.

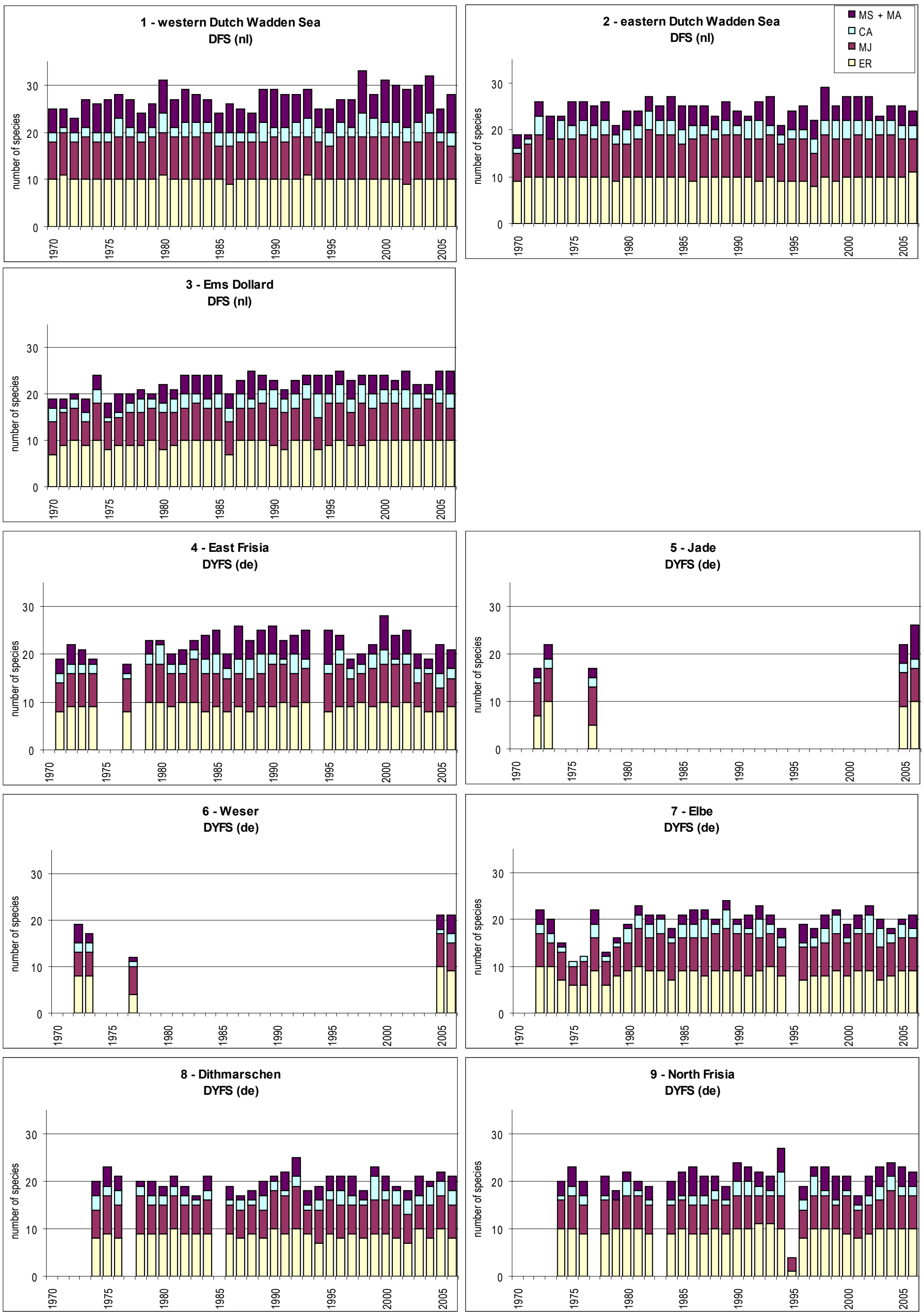


Figure 3: Number of species per year and ecological guild for each region and survey (based on DFSandDYFS; Bolle *et al.*, 2009). DYFS data prior to 1996 are still subject to (ongoing) quality control. ER=estuarine resident, MJ=marine juvenile, CA=catadromous/anadromous, MS/MA=marine seasonal and marine adventitious guild.

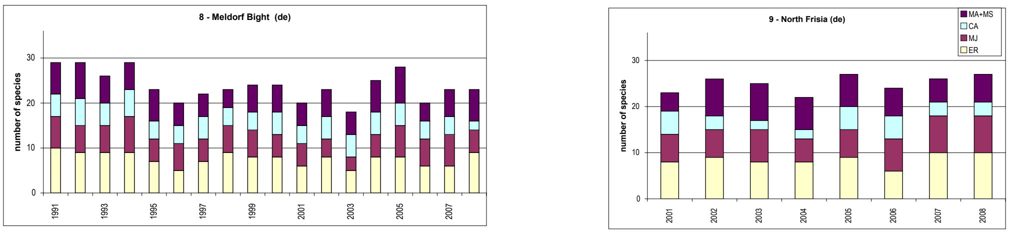


Figure 4: Number of fish species in all catches in August per year and ecological guilds, derived from the Schleswig-Holstein stow net monitoring in the Meldorf Bight (left panel) and Hörnum Deep (right panel). Source: SHS.

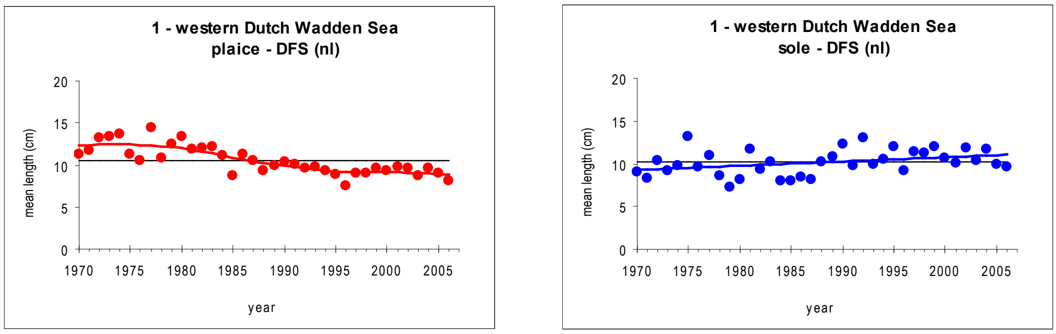


Figure 5: Mean length of plaice (left panel) and sole (right panel) in the western Dutch Wadden Sea. Source: DFS (Bolle *et al.*, 2009).

4. Discussion

4.1 Presence of a typical Wadden Sea fish fauna

To decide if a typical Wadden Sea fish fauna is present (assessing the first target, mentioned in the introduction), the species caught in the fish surveys are compared with the reference species list (Annex I). In the demersal surveys, 11-33 species were observed, which number could be increased with max. 6 to account for the taxonomic grouping. This is at least 14-43% of the amount of (fairly) common species on the reference species list within one year and sub-area. The number of species in the SHS (18-29 in the Meldorf Bight, 22-27 in Hörnum Deep) was max. 38% of the (fairly) common species. These numbers should not be taken too literally since an increased monitoring intensity would result in higher species numbers, because of the positive correlation between the number of hauls and the number of species. Likewise, the aggregation of regions and years would result in higher species numbers. Species richness and composition (number of species per ecological guild) was fairly constant over the observed time-span, at a more or less constant monitoring effort.

4.2 The status of Wadden Sea fish

The broad decrease in fish abundance and biomass in the Wadden Sea since the 1980s, as evidenced by the present results and also described by Tulp *et al.* (2008), seems to be confirmed by data from the western Wadden Sea long-term fyke monitoring by the NIOZ (Van der Veer, unpublished data).

Twaite shad showed a remarkable decline in the Schleswig-Holstein area since 2007, after previous years of higher abundance. Although the Weser and Elbe still sustain twaite shad populations (Bioconsult, 2005; Gerkens and Thiel, 2001), it is questionable whether the species can reproduce successfully in the Ems estuary: the numbers of adults are low, and twaite shad recruitment is very variable (Bioconsult, 2006b). Bottlenecks are found in the upstream parts of the Ems estuary, where unfavourable conditions during summer (oxygen deficits and fluid mud) hamper successful reproduction. This situation also affects the smelt (Scholle *et al.*, 2007b), but the abundance of smelt in the demersal fish surveys does not (yet) indicate significantly declining trends.

Sandeel is not adequately covered in the D(Y)FS, SHS surveys or the WFD monitoring because it lives in a pelagic manner during daytime and then buries itself in the bottom during night. Despite its importance as a food item for sea mammals and birds, which are protected under the Bird and Habitats Directive, no reliable information on the abundance of sandeel in the Wadden Sea area is available.

Herring and sprat are pelagic species, and like the species mentioned above they are not sampled well by the demersal surveys. The initial increase in herring abundance during the 1970s reflects a period of recovery of the collapsed North Sea herring populations after the closure of the fishery

Table 2: Summary of trends in abundance of priority fish species by Wadden Sea sub-area, determined by TrendSpotter analysis of the DFSandDYFS (Bolle *et al.*, 2009). The period in which the trend was significant is indicated. Grey colour means that there was no sampling. Green indicates a significant increasing trend, red a significant decreasing trend in fish abundance of a species. Explanation of the area codes: 1. Western Dutch Wadden Sea, 2. Eastern Dutch Wadden Sea, 3. Ems-Dollard, 4. East Frisia, 7. Elbe, 8. Dithmarschen, 9. North Frisia. * potential data errors, see text.

Twaite shad	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no significant trend
area 2									no trend
area 3									no trend
area 4									no significant trend
area 7									no significant trend
area 8									no significant trend
area 9									no significant trend

Smelt	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									increase>decrease *
area 2									no significant trend
area 3									increase>decrease *
area 4									no significant trend
area 7									increase>decrease
area 8									increase
area 9									increase

Flounder	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no trend
area 2									no trend
area 3									increase
area 4									no significant trend
area 7									increase
area 8									increase
area 9									no significant trend

Eelpout	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									decrease
area 2									increase<decrease
area 3									increase<decrease
area 4									increase<decrease
area 7									no significant trend
area 8									increase<decrease
area 9									decrease

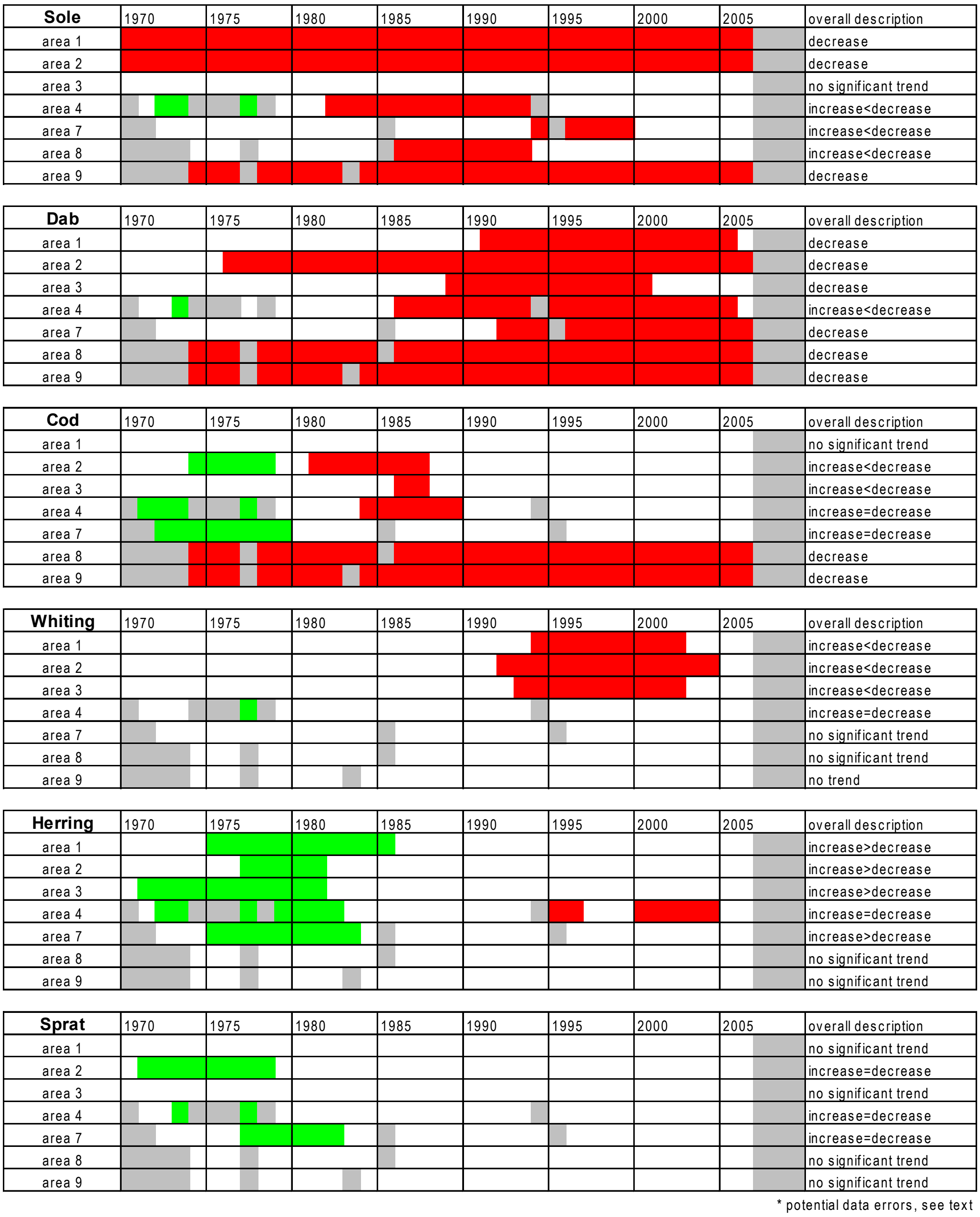
Sandeel	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no trend
area 2									no trend
area 3									no trend
area 4									no significant trend
area 7									increase>decrease *
area 8									no trend
area 9									no trend

Plaice	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									increase=decrease
area 2									increase<decrease
area 3									increase=decrease
area 4									increase=decrease
area 7									no significant trend
area 8									no significant trend
area 9									no significant trend

between 1977 and 1983. Since 2001, poor herring reproduction has been observed for 6 years in a row. Among probable causes are the changes in the hydrography, and a shift in the dominant food items (from *Calanus finmarchicus* to *C. helgolandicus*) (ICES 2007).

The eelpout showed up and down trends, with a significant net decline over the last 35 years. A study on eelpout in the German Wadden Sea showed that thermally limited oxygen delivery in the fish tissues closely matches environmental temperatures (22.5 °C for eelpout) beyond which growth performance and abundance decrease (Pörtner and Knust, 2006). Water temperatures repeatedly exceeded 22.5 °C during summer periods of the 1990s and early 2000s. In the Ems estuary, high exposure to mercury (until 1976) affected the reproduction of eelpout by reduced survival of the fry (Essink, 1989).

The declining abundance of I-group plaice (Vorberg *et al.*, 2005), reflected in the decreasing mean length of plaice in the western Wadden Sea, was masked in the current trend analysis by the still abundant presence of 0-group individuals that dominate the catches. An offshore shift in the spatial distribution of young plaice apparently occurred in the 1990s, which is attributed primarily to a response to increased summer temperatures;



at the same time, decreased predation risk and competition in the offshore areas allowed the juvenile plaice to become more widely distributed (Van Keeken *et al.*, 2007). The shift in distribution of juvenile plaice was also manifest in the German Wadden Sea (Schmidt, 2008).

Dab and sole showed very pronounced decreases in abundance in most of the Wadden Sea sub-areas. Juvenile dab are, unlike plaice, sole or flounder, not confined to coastal nurseries, but can occur over a wide depth-range (Bolle *et al.*, 1994). In autumn, the 0-group migrate inshore and enter the Wadden Sea and estuaries. The catchability of dab fluctuates due to wind stress, temperature and turbidity, although these factors only explain a small proportion of variability in catch numbers (Bolle *et al.*, 2001). Dab catches in the DFS showed an inverse relation with temperature and secchi-depth (>1 m), although dab density seemed to decrease again at secchi-depths of <1 m (Bolle *et al.*, 2001). Increasing catches in the BTS (beam trawl survey, North Sea) indicate that the decrease in juvenile dab abundance in the Wadden Sea must be the consequence of a distribution shift toward offshore waters (Bolle *et al.*, 2001). The decreasing abundance of sole concerned all age groups, since the mean length in the demersal surveys remained more or less constant. A dynamic factor analysis

(DFA) indicated for the Wadden Sea a best-fit-model with the number of seals and beam trawl intensity as the two dominant environmental variables. In this model, sole showed a significant negative relation with beam trawl effort (Tulp *et al.*, 2008).

The period of increasing trend in cod abundance in the Wadden Sea until the early 1980s reflects the 'gadoid outburst' of the 1960s and 1970s that occurred in the North Sea (Hislop, 1996; Beaugrand *et al.,* 2003). Cod recruitment is affected by overfishing and fluctuations in plankton; the survival of larval cod depends on mean size of its prey, seasonal timing and prey abundance. Beaugrand *et al.* (2003) conclude that rising temperature since the mid-1980s has modified the plankton ecosystem in a way that reduces survival of young cod. It seems therefore likely that the present low abundance of cod in the Wadden Sea is mainly connected with processes acting in the North Sea. Whiting recruitment since 2002 has been below the long-term average, probably due to low stock size and environmental factors (ICES, 2008). The abundance of whiting in the Wadden Sea reflects the North Sea recruitment.

The recently experienced climatic changes have led to consequent changes in fish abundance, sometimes outranging the long-term average. The marine juvenile fish species in the Wadden Sea seem to reflect the heavy fishing pressure in the North Sea in combination with the climatic and hydrographic changes. The abundance of several other (estuarine resident) fish species also decreased to levels below the long-term average, but factors (natural or anthropogenic) causing these changes are still largely unknown.

4.3 Assessing the status of Wadden Sea fish

The assessment of fish in estuaries has been advanced by the requirements of the WFD, which urged the development of an assessment tool and according (fish) monitoring. For Wadden Sea fish, a first step toward a common assessment and the selection of suitable underlying metrics has been made, but further development is needed to end up with an applicable tool. The selected metrics each have their limitations and need to be evaluated and adapted if necessary. Species richness can only be compared between years and areas if monitoring effort is the same and constant between years. The species composition (number of species by ecological guild) is less dependent on the presence of individual species, but focuses on the functional aspects of the fish fauna. On the other hand, this metric appears not very sensitive in detecting changes that occur in the Wadden Sea. By looking at the mean length, the distribution shift occurring in some species or specific age-groups remains concealed. Abundance by age group/length class may be more revealing in this respect.

The joint analysis resulted in a more detailed and robust description of long-term trends in fish species. By applying the TrendSpotter methodology, a more objective way of determining the trends in abundance became available. The spatial resolution is now to the level of QSR sub-areas, which gives much more detail than the previous QSR 2004 which considered only the Dutch or German Wadden Sea. A next step might be to correlate the relevant explanatory parameters (as formulated in hypotheses, based on expert knowledge of the ecology of the species concerned) to fish metrics. For this purpose, an overview of available abiotic data has already been made on a meta-data level (Bolle *et al.*, 2007).

Focusing on priority species brings the risk of overlooking developments in other fish species, but the existing Wadden Sea fish monitoring has its limitations for analysing trends in the fish fauna. Fortunately, the newly installed WFD monitoring provides additional information for the status of fish in the estuaries. The status of fish in nearly all WFD transitional waters bordering the Wadden Sea shows moderate to large deviations from the 'undisturbed' situation for natural estuaries. Although species composition is still considered to resemble reference conditions, with the exception of the number of diadromous species, the abundance of typical indicator species is currently at a very low level compared to the situation of the early 20th century (Bioconsult, 2008).

Although we might like to draw conclusions on the status of the Wadden Sea fish in terms of 'good', 'moderate' or 'poor', from a scientific point of view it is not possible to give such qualifications to the outcome of the analyses due to the present lack of knowledge on the causal factors underlying the changes observed in the Wadden Sea. Many of the selected fish species are influenced to a large extent by natural variations, the causes of variation are hardly understood and our knowledge is not sufficiently advanced to allow this kind of judgement. Furthermore, (historic) reference conditions are not known; but even if they were, one might ask why it would be desirable to go back to the status of a hundred (why not a thousand?) years before.

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Changes of abundance and distribution of young plaice (*Pleuronectes platessa*) in the Schleswig-Holstein Wadden Sea (Germany) in the last +20 years

Katharina Schmidt, Thomas Neudecker, Institute of Sea Fisheries, Hamburg,
katharina_schmidt_83@yahoo.de, thomas.neudecker@vti.bund.de

1. Introduction

The Wadden Sea is a complex area of habitats on a small spatial scale (Vorberg and Breckling, 1999). Ebb and flood generate periodical and intensive changes while sea surface temperatures exhibit daily, seasonal and annual fluctuations which are determined by the intensity of the North Atlantic Oscillation (Becker, 2003; Sterr, 2003). As North Sea plaice (*Pleuronectes platessa*) 0-groups have their nursery grounds in the area, finding suitable habitats and food there before they leave for the open North Sea (*e.g.* Vorberg and Breckling, 1999), the young fish are exposed to these intense changes and may be affected by them.

While it is the main aim of the Demersal Young Fish Survey (DYFS) to provide the assessments of year class strengths of juvenile plaice in order to assist the annual fish stock assessments of the relevant ICES (International Council for the Exploration of the Sea) working groups (WGNSSK and WGBEAM: www.ICES.dk, Bundesforschungsanstalt für Fischerei, 2005), the data gained can also be used for other purposes. This paper examines the variation of parameters, especially water temperature, water depth and distance towards the coastline, possibly affecting abundance and distribution of 0-group plaice.

2. Material and Methods

The DYFS has taken place annually in September to October since 1972 (Neudecker, 2001). During these surveys within the Wadden Sea catches of young plaice and more than 40 other fish species are counted, measured and weighed. These data are recorded against numerous parameters which characterise catch conditions, e.g. sea surface temperature, water depth, salinity, tidal phase, weather conditions, together with date and time.

To detect changes in parameters and their effect on juvenile plaice two subsets of the available DYFS data series have been compared originating from the Schleswig-Holstein Wadden Sea region. Three tidal gully systems were fished, "Aue" (in the north), "Hever" (centre) and "Piep" (in the south) as well as some positions further offshore along the 10m depth contour. During the second phase, some further positions in the gully system called "Hörnum Tief", further north, were also surveyed. Each subset contained data from five years: 1987 to 1991 and from 2002 to 2006 (Table 1). The numbers of fish caught were standardised to an area of 1000 m² for comparability.

Sea surface temperature and water depth were correlated with plaice abundance, depth data being grouped to four strata from 0-5 m, 6-10 m, 11-15 m and 16-25 m (Table 2).

However, as water depth is recorded as the approximate mean depth during a haul, which may cover quite different depths in the highly structured channel systems of the Wadden Sea thereby possibly biasing depth information, a further approach was chosen. As water depth principally increases with distance from the coastline and especially the outer limits of the tidal flats, that external boundary has been drawn on the topographical maps using ArcMap™ following an approach suggested by Kohlus (pers. comm., 2007). That basic boundary is defined by permanent water coverage during regular low tide west of the chain of tidal flats, sand banks and

Water depth [m]	1987 until 1991	2002 until 2006
0 – 5	68,9 %	55,7 %
6 – 10	27,3 %	33,8 %
11 – 15	3,8 %	8,6 %
16 – 25	no record	1,9 %

Table 2 (left): The proportion of the measured young plaice (2 cm until 16 cm) in relation to water depth

Table 1 (bottom): Basic data of the DYFS for the periods 1987 – 1991 and 2002 – 2006.

Period	1987 - 1991	2002 - 2006
Number of hauls	278	347
Hauls containing plaice	273	303
Total sum of plaice caught (counts extrapolated to total catch)	20.887	6.962
Total sum of plaice caught standardised to n / 1000 m²	5.266	1.577
Maximum number of plaice in one haul per 1000 m²	247	66

islands and follows roughly the national base line. It has been paralleled by several additional lines with distances of 8 km from each other, forming a total of six "buffer zones" of the same extent but increasing distance from the coast line. In this way, spatial (and correlated depth) shifts could be analysed for length frequencies of plaice and the proportion of young plaice per buffer zone.

ACCESS™ and EXCEL™ were used for processing data and an ArcGIS™ analysis provided the visualisation of spatial data in maps.

3. Results and Discussion

3.1 Spatial distribution of hauls and plaice abundance

Figure 1 (1987-1991) and Figure 2 (2002-2006) show the pooled and standardised data (n/1000m²) of all plaice caught from the data subsets and for each haul position. The comparison of the two figures indicates a decline in the numbers of plaice caught. This can be also seen from Table 1. Despite an increase in the number of hauls between the first and the second period (278 hauls from 1987 to 1991 compared with 347 from 2002 to 2006), the total number of plaice caught, standardised catch rates and maximum catch rates show a strong decline which has been observed all over the Wadden Sea (Jager *et al.*, 2009).

An analysis of single year and regional data over the entire time series appears to be useful to find out about abundance shifts which seem to occur between periods and gully systems looking at the differences between Figures 1 and 2.

Berghahn (1983), Fox *et al.* (2000) and Van Keeken *et al.* (2007) describe sea surface temperature as one important factor for abundance and distribution, water depth being another (Berghahn, 1983; Van der Veer and Bergman, 1986) as well as time of day (Burrows *et al.*, 1994; Gibson *et al.*, 1998) and tidal phase (Berghahn, 1983; Van der Veer and Bergman, 1986). Furthermore, competition between numerous young plaice may affect abundance, distribution and growth (Neudecker, 2002; Pihl *et al.*, 2000; Van Keeken *et al.*, 2007).

3.2 Shift of abundance by water depth

The results for the proportion of young plaice per depth stratum are listed in Table 2. In the shallow waters of the first stratum (depths between 0 and 5 metres) 68.9% of the plaice were caught

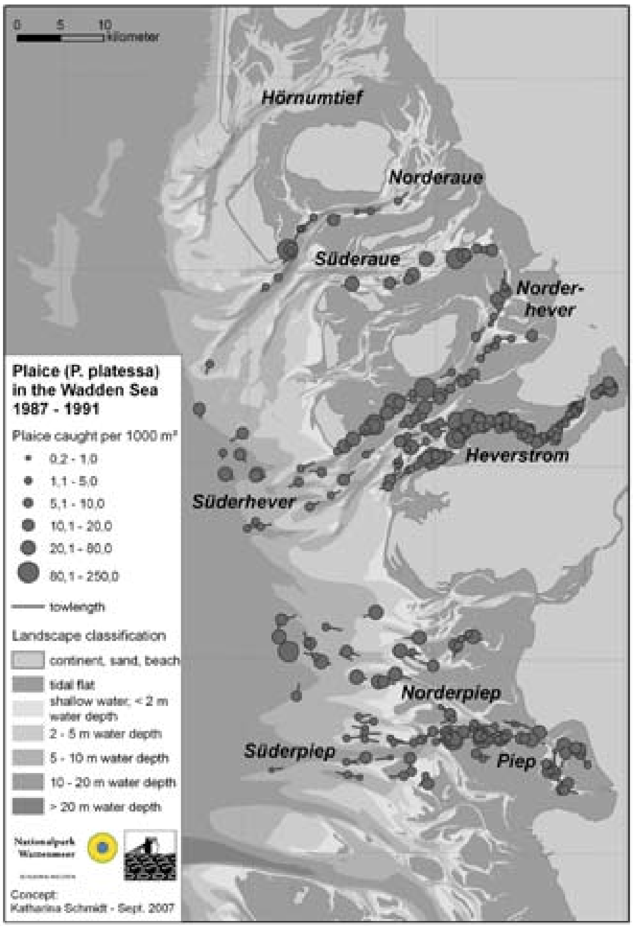

Figure 1 (bottom left): Abundance and distribution of the DYFS catches of North Sea plaice in the Schleswig-Holstein Wadden Sea, 1987 until 1991. Italics in the map are the names of the tidal gullies.

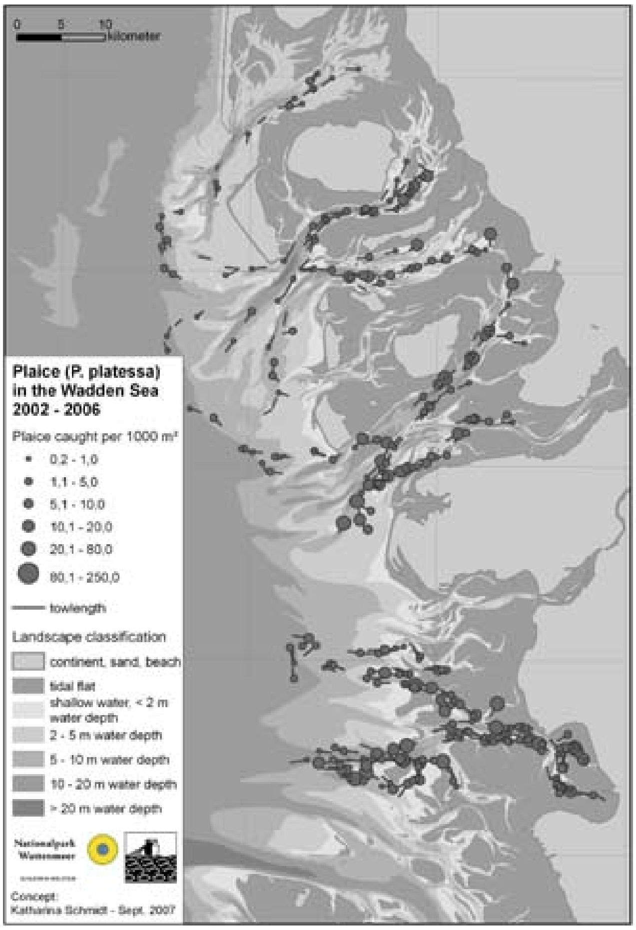

Figure 2 (bottom right): Abundance and distribution of the DYFS catches of North Sea plaice in the Schleswig-Holstein Wadden Sea, 2002 until 2006.

during the first period while only 55.7% of these fish were caught in the same stratum during the second period. The second stratum (6 to 10 m) reveals only 27.3 % of the plaice for the first period while 33.8 % were caught here during the second period. The same trend occurs in the third stratum (11 to 15 m), *i.e.* 3.8 % of plaice for the first period versus 8.6 % for the second period. No comparison is possible though for stratum 4 (16 to 25 m) due to the lack of data from the first period. Nevertheless these depth stratified data show a shift towards deeper water between the two periods, which is in line with the observation of Van Keeken *et al.* (2007) from Dutch waters. Therefore, one can conclude that the shift in juvenile plaice abundance towards deeper water may be valid for the entire Wadden Sea. However, data from East Frisia and the Elbe estuary have not yet been evaluated and may give different results.

3.3 Shift in spatial distribution

Table 2 reflects the water depth without regard to an offshore shift as deeper parts can also be observed in the channels of the inner Wadden Sea. Therefore the proportion of fish caught in each buffer zone has been plotted in Figure 3. No comparisons are possible for buffer zones 1 and 6 (the furthest offshore, *i.e.* westerly area and the eastern-most area nearest to the shore) due to the lack of data in these regions from the second period. However, the two comparable and further offshore buffer zones 2 and 3 show for the second period (2002 until 2006) a much higher proportion of juvenile plaice compared to the earlier period (1987 until 1991), which is further proof of the change of abundance and distribution of these fish in the Schleswig-Holstein Wadden Sea. Accordingly, buffer zone 4 - representing an inner part of the Wadden Sea proper - shows a higher proportion of juvenile plaice for the first period. In the remaining buffer zone 5 there is only a small difference.

This strengthens the observation that the distributional range of young plaice has changed – in German as in Dutch waters – to the deeper and more offshore areas during the last twenty years, though only two five year periods have been analysed. The remaining data from the Schleswig-Holstein part of the Wadden Sea as well as from other parts - beginning already in 1974 - should also be checked and analysed since the observed change might be valid only for the investigated time spans.

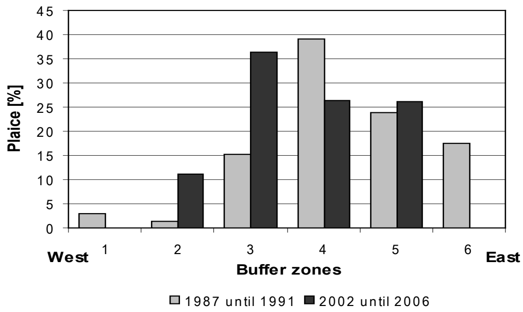

Figure 3:
Proportion of young plaice per buffer zone.

3.4 Sea surface temperatures

DYFS data show an increase of sea surface temperature from the first to the second time period. The range was 11 °C to 17 °C within the first period and 15 °C to 21 °C in the later one (Figure 4 and 5) which corresponds well with the SST (Sea Surface Temperature) charts published by http://www.bsh.de and the data time series supplied by the harbour authorities of Büsum (Schmidt, 2008).

Both graphs give the total number of plaice caught per 1000 m² by temperature recorded. The numbers above the columns give the number of hauls at the particular temperature.

Two maxima in Figure 4 reflect different autumn temperature regimes within the years during the first survey period while the second period (Figure 5) was more homogenous in temperature regimes but higher.

It is assumed that year class strengths (and observed levels of abundance) of plaice are independent of ambient SST during the autumn surveys as winter SST correlates with year class strengths according to Fox *et al.* (2000). On the

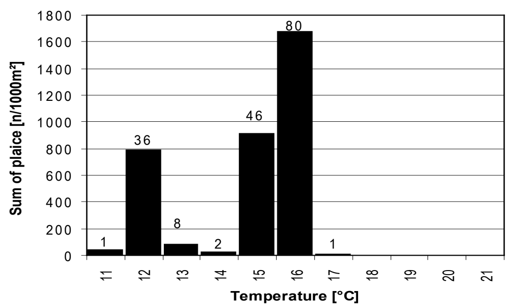

Figure 4:
Sum of plaice caught during period 1987 until 1991 at ambient temperatures. Numbers above columns give number of hauls at particular temperature.

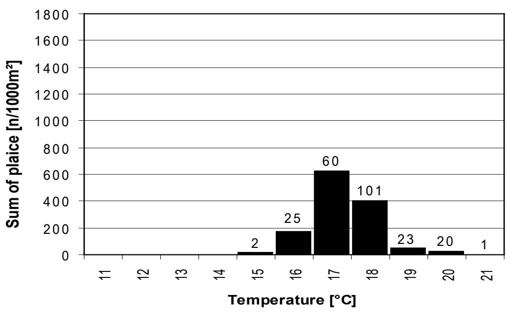

Figure 5:
Sum of plaice caught during period 2002 until 2006 at ambient temperatures. Numbers above columns give number of hauls at particular temperature

other hand the increased summer and autumn SST accelerates metabolism and growth. This might lead to an earlier seaward migration of the young fish and therefore the observed shift to the more offshore and deeper waters can be explained principally by the temperature difference between the two periods.

Whether the warming up of the Southern North Sea (Ehrich *et al*., 2007) and the Wadden Sea in particular is a matter of climatic fluctuations like the repetitive peaks of the eight year cycle of the North Atlantic Oscillation (NAO) (Becker and Pauly, 1996) - and therefore reversible with the change of NAO - or a continuous development driven by climate change remains an open question.

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How to deal with alien species in the Wadden Sea?

Karsten Reise, Alfred Wegener Institute for Polar and Marine Research, Wadden Sea Station List/Sylt, Germany; Karsten.Reise@awi.de

Abstract

Compared to other coasts in the world, the Wadden Sea is moderately affected by introduced alien species. However, some invaders exert strong effects on habitat properties and recipient biota. The problem is not a threat to native species but a change in the balance of species populations towards a dominance by universal invaders. The natural heritage will never be as before. Therefore, alien invasions are worse than the reversible effects of oil spills, eutrophication or small-scale disturbances. Preventing introductions of alien species is an international challenge, and Wadden Sea states should not further delay ratification of conventions against the use of alien species in aquaculture and on the treatment of ship ballast to reduce unintended introductions. There is an urgent need for a trilateral management plan on how to deal with alien species in the Wadden Sea: raising awareness and a common portal could help in identifications, conducting inventories and species specific risk assessments, specifying targets, enforcing preventions of introductions, improving early detection and control measures. Aliens have primarily strengthened the lower levels of the food web, and management could improve top-down control by native consumers of alien prey by restoring lost upper level species. Accommodation capacity for species could be raised by restoring lost habitats.

1. Introduction

Introduced alien species are also called non-native species or, more formally, neobiota. This term does not cover species which immigrate on their own, for example fish swimming into a warmer North Sea. Neobiota are defined as species or genotypes which arrived in a region because humans have carried them beyond their natural range of dispersal. In the Wadden Sea, aliens have been either accidentally introduced with ships, have immigrated through canals or have been imported to improve coastal resources. Also, many aliens have been first introduced to adjacent coastal regions, and from there have colonized the Wadden Sea by natural dispersal.

Alien species have been extensively treated in the Wadden Sea Quality Status Reports (Reise *et al.*, 2005; Nehring *et al.*, 2009 and references therein) and discussed at the 12th International Scientific Wadden Sea Symposium in Wilhelmshaven 2009. This chapter is intended to summarize the present state of affairs and to discuss what can be done about it. Opinions and attitudes towards alien species are divided (*i.e.*, Simberloff, 2003; Larson, 2007), and this author is to be blamed for his distortions of the problem.

2. What is the problem?

The Wadden Sea is subject to a rising tide of invading species (Figure 1). Some arrive on their own to realize 'warmer' niches in the wake of climate change. One may regret such immigrations, but the only feasible countermeasure is to reduce burning of fossil carbon and forests. However, this article is concerned with the intentionally or unintentionally introduced alien species by human vectors. Some aliens have been firmly established for several decades but remained inconspicuous, while others have recently arrived and quickly attained dominance. Some invading populations first boom, then bust and then linger on. Still others remained at small population size but then proliferated with the onset of climatic warming. Increasing connectivity in global trade, combined with global warming, is expected to facilitate further invasions of alien species. In the Wadden Sea, eutrophication and structures for coastal defence and shipping may also benefit the establishment of aliens. The former provides an ample supply of phytoplankton to invading suspension feeders, while the latter ease the establishment of fouling invaders such as ascidians, oysters, barnacles and macroalgae.

It has generally been stated that alien species constitute a major threat to native biota and habitats. An often used example are goats released on oceanic islands where large herbivores were absent before. Such introductions entailed dramatic losses in endemic plants. However, species introduced into the Wadden Sea do not resemble goats, and the effects of aliens are different in the Wadden Sea compared to isolated islands with evolutionary deficiencies. The Wadden Sea is part of a continuous coast at the Northeast Atlantic, and it emerged around 8,000 years ago

Figure 1:
Alien species in the Wadden Sea (from top left to bottom right): the red algae *Gracilaria vermiculophylla* arrived from the Pacific early in the 2000s; *Mnemiopsis leidyi* is an American comb jelly common since 2006; the mitten crab *Eriocheir sinensis* arrived in the previous century from China; the Pacific oyster *C. gigas* has been introduced in the 1980s for the gourmet market; the ragworm *Nereis virens* appeared early in the previous century and may originate from North America; the grass *Spartina anglica* has been introduced to facilitate mud accretion; the sea-squirt *Styela clava* and the skeleton shrimp *Caprella mutica* stem from the Pacific and are found mainly in marinas since the late 1990s; sanderling feeding on introduced razor clams *Ensis americanus* left over by gulls and oystercatcher; the introduced Australian barnacle *Elminius modestus* and the American slipper limpet *Crepidula fornicata* are proliferating since the onset of global warming; the large brown alga *Sargassum muticum* arrived with Pacific oysters; the shipworm *Teredo navalis* is of unknown origin and perforates wooden structures.

with its characteristic suite of habitats. Endemic species are almost absent and recurrent long glacial and short interglacial periods have limited the regional evolution of advanced species interaction complexes as known from coral reefs. In the Wadden Sea, invasive species encounter few hurdles against establishment and find plenty of resources. The recipient biota are usually versatile enough to survive alongside the invaders.

Nevertheless, introduced alien species have considerably transformed habitats, displaced native species, restructured the food web and altered material cycling in the Wadden Sea. Whether these changes are perceived as good, bad or ugly depends on the perspective taken. Phrases like "alien species are causing a reduction in ecological status", "pose a major and fast growing threat to native biodiversity" or "threaten the integrity of ecosystems" are often used, yet obscure what is really going on and are too vague and too general as a basis for management decisions. Alien species interact in multiple ways with natives, other aliens and with habitats in the recipient ecosystem, and it is a challenge to quantify or rank their net impact. We have to dive into some of these details to avoid simplistic 'solutions'.

Aliens may find empty habitats without competing with natives for space and food. An example is the American razor clam *Ensis (directus) americanus* in the shallow subtidal zone. Instead of competing with other bivalves, its large biomass serves as an additional food source for coastal birds like diving ducks or, during exceptionally low tides, also oystercatcher, herring gulls and others. However, razor clams feed on phytoplankton transported to and fro with the tides, and thus although no other clam may live in the vicinity, long-distance competition for this planktonic food with other suspension feeders in the coastal zone is potentially possible. Up to now, there is no evidence of this, and other alien suspension feeders have recently become abundant in the Wadden Sea as well which does not suggest that food is limiting such invasions. Most notable are the invasions of the American slipper limpet *Crepidula fornicata* and the Pacific oyster *Crassostrea gigas*, and there are many other aliens adding to this trophic guild of suspension feeders in the Wadden Sea. Together these have apparently strengthened and diversified the coastal filter function.

Many mussel beds in the Wadden Sea have been overtaken by the invasive Pacific oysters. There, the native mussel *Mytilus edulis* is now relegated to interstices between the much larger oysters. A reversal to beds dominated by mussels seems unlikely as long as the climate remains favourable to the recruitment of oysters. Dominance has been passed over from mussels to oysters. As a minor compensation, mussels find a refuge among oysters. Eider ducks which used to prey on mussels can hardly get them any more, and the oysters cannot be swallowed. These ducks have to leave or turn to other prey. The strong oyster shells are also a challenge to other consumers. Invasive oysters constitute largely a dead end in the food web of the Wadden Sea. As a side effect, these oysters also serve as a sink for larval trematode parasites. These encapsulate in the oysters and from there never get to their final avian hosts.

In the shallow subtidal zone, Pacific oysters and stacks of slipper limpets provide anchorage for an alien alga, *Sargassum muticum*, which, growing to lengths of > 3 m, is much larger than any of the native algae in the Wadden Sea. It forms meadows of a structure not unlike subtidal seagrass beds which were wiped out in the Wadden Sea by an epidemic disease in the 1930s and have never recovered. The combination of alien oysters, slippers and this brown alga generates a habitat rich in foul material. This enables other associated organisms, both of native and alien origin, to flourish. The resulting biodiversity is much higher compared to what has been there before the arrival of these aliens.

To summarize the above, introduced alien species have rather mixed effects on the Wadden Sea ecosystem: some provide additional food to birds (*i.e.* razor clams) while others (*i.e.* oysters) deprive birds of food; some displace native species (*i.e.* oysters) while others (*i.e. Sargassum*-algae) raise biodiversity by habitat provision. A net balance of these manifold effects is hard to determine and may vary in space and time.

Inevitably, there will be winners and losers associated with the rising tide of alien species sweeping into the Wadden Sea. Aliens mainly enrich the lower levels of the trophic web with primary producers, herbivores and small omnivores. On the other hand, the upper levels are still under-represented due to historical hunting and continuing overfishing. It is hard to estimate how the presence of sturgeon would have affected alien suspension feeders if this large fish still populated the Wadden Sea as it did a century ago.

With every new alien invading, the Wadden Sea ecosystem further diverges from its natural state. Nature conservation in the sense of preserving the natural species composition is in vain. More and more universal invaders achieve dominance. The biotic assemblage of the Wadden Sea becomes more and more similar to that of other shallow and sheltered sedimentary coasts within the temperate climate zones. With at least 50 alien taxa currently recognized in the brackish and marine aquatic parts of the Wadden Sea, this coast is moderately infected with aliens. More enclosed coastal water bodies such as San Francisco Bay or Chesapeake Bay contain more (Ruiz *et al.*, 1997). The small Oosterschelde estuary not far from the Wadden Sea has more aliens, presumably because of intensive shellfish cultures (Wolff, 2005). More exposed coasts like those of the British Isles or the cold Norwegian Fjords with little international shipping have received a smaller amount of aliens (Leppäkoski *et al.*, 2000). Close to the Suez Canal along the Mediterranean shores, numbers of aliens are extremely high (Galil, 2009). With ongoing uncontrolled species introductions, the Wadden Sea coastal biota will become more diverse but at the same time lose its regional special quality. This process has been termed *biological homogenization* or 'MacDonaldization' (McKinney and Lockwood 1999; Olden *et al.*, 2004).

The Wadden Sea is regarded as a tidal wetland of outstanding universal value and is on the UNESCO World Heritage List. Notwithstanding, the biotic component is progressively changed by alien invaders towards a universal assemblage of fortuitous composition. From a functional perspective of the ecosystem or of the material services it provides to humanity, this may not matter very much as a whole, but only in the details. However, our vision of a 'natural heritage' is increasingly undermined by the ongoing invasions of alien species. They constitute an ethical problem. There is a societal desire to preserve naturally developing parts of our environment for coming generations. These areas are viewed as counterbalances to urban environments or cultivated land, as resources for evolved genotypes, as valuable reserves for education and scientific studies, as well as for inspiration.

It is our responsibility to preserve this natural heritage with as little human-caused changes as possible and to restore a natural state if feasible. In this sense, introductions of alien species should be minimized, and in view of the accelerating rate of alien invasions we should no longer hesitate to do this.

3. How bad are alien invaders?

This question may be answered either species by species (Thieltges *et al.*, 2006) or generally in comparison to other environmental pressures. With regard to an individual species, it is obviously important whether it affects human health, causes economic harm, remains inconspicuous or strikingly changes the environment and affects popular or otherwise desirable native species. Also, alien invaders may themselves be highly popular or useful, for example the cute raccoons introduced from America to Europe, or the ornamental *Rosa rugosa* introduced from East Asia and invading the dunes of the Wadden Sea islands. In each case, the pros and cons need to be evaluated and sometimes the public has to be interviewed to reach a consensus as to what extent an alien species is acceptable or requires measures of control.

In comparison to other environmental pressures, alien species hold an intermediate position. Effects of oil spills, eutrophication and small-scale disturbances can be dramatic but are essentially reversible after the pressure has been stopped or reduced. Once established in a recipient region, particularly in a marine environment, alien species are hard, often impossible, to remove. Even after eradication, it is likely that the alien invader had already induced evolutionary changes in the recipient biota or habitat changes which can never be restored. Aliens transform ecosystems irreversibly, and thus their effects should be ranked higher relative to the reversible effects of other environmental pressures.

However, there are other pressures which entail irreversible effects. Examples are a complete habitat loss, the extinction of species caused by unsustainable fishery or hunting, and the release of persistent pollutants into the natural environment. These may be even worse than alien species. The latter represent products of natural evolution albeit having evolved in another context. Once aliens are firmly established and no acceptable control measures are at hand, they should not be treated differently from native species, and then ethical norms do not justify a distinction anymore.

4. What could be done in general?

There are several international conventions for nature conservation which also address alien species (*i.e.*, the Rio Convention of Biological Diversity 1992/2002, the Bonn Convention on migratory species of wild animals 1980, the Bern Convention on European wildlife and natural habitats 1979, the Ramsar Convention on wetlands of international importance as waterfowl habitats 1994). All express concern about alien species and give guidelines to prevent introductions and to control or eliminate already introduced species. However, only a few states have so far adopted strict rules against the introduction of alien species. Therefore, the global effect of the conventions is still low. The most general reason for this frustrating state of affairs is presumably the low public awareness on the issue of introduced alien species (European Commission, 2009). Concerted campaigns could help.

There are also potential legal instruments which are specifically relevant for aliens in the aquatic biota of the Wadden Sea. One concerns regulations on the use of alien and locally absent species in the European aquaculture industry (Council of Europe 2007). The other is about control and management of ship's ballast by the International Maritime Organization (IMO 2004). Ballast water is one of the major vectors in the spread of alien aquatic species. However, both conventions have not been ratified by a sufficient number of member states to set these conventions into force. The Wadden Sea states are among those which still have to ratify, and they should do this without delay.

5. What can be done in the Wadden Sea?

The problem of alien species is complex: approaches for terrestrial, limnic and coastal waters differ to some extent, opinions among experts are often divided and individual states follow similar but not identical strategies. To reach consensus with regard to aliens in the trilateral Wadden Sea nature area, a trilateral working group on aliens in the Wadden Sea should be implemented with the following urgent tasks:

- to conduct inventories and design a trilateral monitoring of alien species and genotypes, assess risks, help in identifications and to raise awareness on introduced alien species,
- to define trilateral targets on alien species, genotypes and genetically modified organisms,
- to develop a trilateral management plan for aliens with guidelines for prevention, early detection and control.

The shared vision of the trilateral Wadden Sea nature area is "a healthy environment which maintains the diversity of habitats and species, its ecological integrity and resilience as a global responsibility" (Stade Declaration, 1997, p. 17). There is no doubt that introduced alien species are capable of altering habitats and species spectra, may disrupt the ecological integrity and affect resilience. Yet, none of the targets in the Trilateral Wadden Sea Plan considers the impact of alien species.

Therefore an alien species management plan at the level of the Trilateral Cooperation on the Protection of the Wadden Sea needs to be developed.

Attempts to prevent alien species introductions cannot be perfect and more can be done. In addition to a ban on intended introductions and strong efforts to prevent accidental introductions, regular monitoring and genetic screening on new alien species and introduced genotypes can be combined with immediate elimination campaigns to stop their establishment within the Wadden Sea whenever feasible. Aliens have primarily strengthened the lower levels of the Wadden Sea food web (see Byrnes *et al.,* 2007), and management could improve top-down control by native consumers on alien prey by restoring lost upper level species. Restoring lost habitats could raise the accommodation capacity for aliens alongside natives.

In particular, invasive alien species which transform habitats, and which already have or are known to have negative impacts on native species should be controlled to minimize their impact. Applied methods should be carefully selected and tested with respect to optimal species specificity, expected long-term success, costs and public acceptance. If no control measures are feasible or the action would entail ongoing human disturbances in the protected area, then the presence of such resident aliens should not be used to downgrade the Wadden Sea in the quality ranking of the European Water Framework Directive (but see Cardoso and Free, 2008). This coastal wetland can accommodate and integrate alien species to some extent but stringent measures to stem the tide of alien invasions are needed to preserve our natural heritage.

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Habitat Definition and Monitoring

Applied vegetation mapping of large-scale areas based on high resolution aerial photographs – a combined method of remote sensing, GIS and near comprehensive field verification.

Jörg Petersen, Otto Dassau, Hans-Peter Dauck and Nicole Janinhoff, nature-consult, Hildesheim, Germany, http://www.nature-consult.de, office@nature-consult.de

Abstract

Nature-consult has developed and established a method that combines classical vegetation mapping with modern methods of multi-spectral image interpretation. The technique combines specific knowledge of the disciplines vegetation ecology, GIS and remote sensing to produce maps of a very high quality, geometric accuracy and coincident efficiency.

This methodology is described and important notes for implementation in similar vegetation mapping projects are given. Additionally the method is documented as the basis of four reference projects carried out for the Wadden Sea National Park Administrations of Lower Saxony and Schleswig-Holstein, the German Federal Institution for Hydrology (BfG) and the Federal Administration of Waterways and Shipping (WSA-Bremerhaven). Within these projects, different high resolution camera systems – matrix cameras (UltraCam-D, DMC) and line scanner (HRSC-AX) – were used.

1. Introduction

Today, as in the past, mapping in the field is the most important and most exact way to document current vegetation conditions. These data provide insight into existing conditions and arising changes. For example, they provide an important resource needed to fulfil nature conservation, coastal conservation and general planning requirements. In this context, typical tasks and reporting obligations include Natura 2000, the EU Water Framework Directive, the Trilateral Monitoring and Assessment Program (TMAP), Major Nature Reserves, and Environmental Impact Assessment (EIA).

For vegetation mapping, the evaluation and analysis of digital (multi-spectral) imagery plays an important role. This is particularly true if the area under investigation and to be mapped is very large, resulting in time and budgetary constraints. Recent methods concentrate either on classical vegetation mapping in the field, where aerial images are used exclusively as background maps, or on pure digital image analysis by means of vegetation classification with little verification in the field. The nature-consult approach combines the advantages of classical vegetation mapping, modern remote sensing and Geographical Information Systems (GIS) analysis. This 'direct' co-operation of vegetation, GIS, and remote sensing experts is a requirement for the successful implementation of this method.

2. Applied method (6 working steps)

In the course of several projects this future-oriented approach implementing remote sensing to support vegetation mapping was designed, used and developed further (Figure 1).

Data pre-processing (2.1)

Prior to each project, selection of the vegetation units which have to be surveyed takes place. For priority areas, a finely differentiated classification is used. For thematic boundary regions, a somewhat rougher subdivision of vegetation types turned out to be optimal (BfN, 2001; Drachenfels. 2004). Generally speaking, 'less is more' in terms of a vegetation classification.

If, at the beginning of a project, the aerial flight has not yet been undertaken, an additional consultation takes place. During this process a data requirements analysis is carried out to determine which data (aerial photographs, elevation data) are useful and necessary for the survey. At the

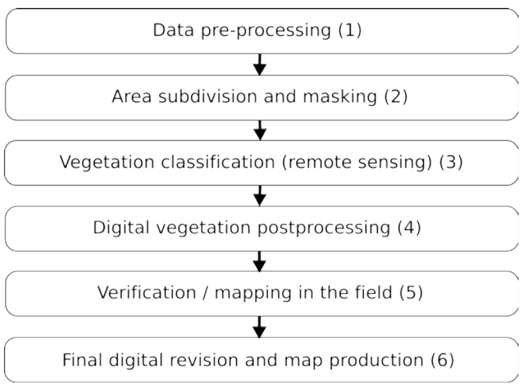

Figure 1: General overview of the applied method (working steps).

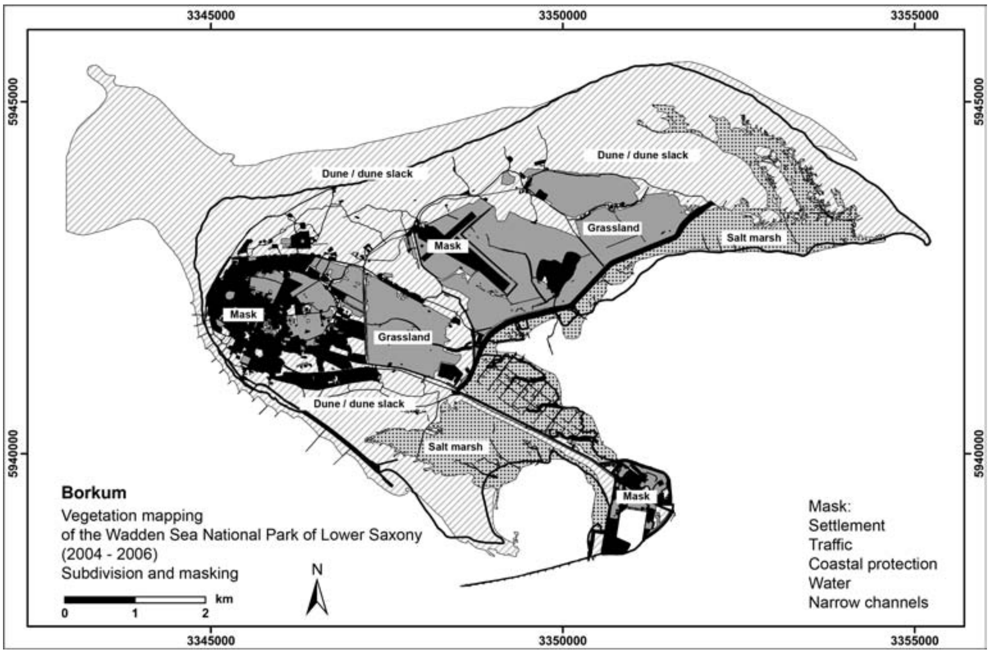

Figure 2: Categorization and masking example for the East Frisian Island Borkum (Advantage: Separate classification of dune/dune valleys, salt meadows and grassland; for a project summary see Table 1).

same time, decisions are made as to how the data processing should be carried out in order to obtain optimal analysis results for the classification. The differentiation of vegetation units places special requirements on the aerial photographs to be used for the project.

For pre-processing of aerial imagery, image enhancements are used to reduce radiometric and geometric distortions which occur during data acquisition. Typical analyses are contrast enhancement, digital filtering, fourier transforms and principal component analysis (Schowengerdt, 2007).

The collection and integration of additional vegetation related data plays an increasingly important role for vegetation classification of multi-spectral aerial photographs. These 'artificial' channels can provide additional information about elevation, geology, texture, slope, or soil characteristics for the area under investigation (Albertz, 2007).

Area subdivision and masking (2.2)

Before classification, areas which do not have to be analysed are masked to define and minimize the area size and the amount of information to be processed. The goal is to reduce the number of vegetation units in order to optimize the classification result. If possible, mask elements such as roads or settlements are taken from official data (ALK, ATKIS or DBWK2). This allows the customer later to exactly overlay the project data with topographic and other maps for visualization and further analyses.

Carrying out an unsupervised classification of the aerial imagery data first is often helpful. For example, it can be used to identify and integrate water surfaces into the mask. However, in practice it is often necessary to digitize mask elements manually during mask creation.

Classification and filtering (2.3)

Training areas are the basis of the applied classification method. These assign specific spectral characteristics to the different vegetation units and are used for their separation into different classes. During the definition of vegetation units, it is important to make sure that the spectral characteristics of the training data are differentiated as clearly as possible (Jähne, 2005). For interpretation purposes, frequency distributions of the training data can be derived and visualized as one or multi-dimensional spectral plots (Lillesand *et al.,* 2003, Figure 3).

Training areas are defined over the entire area under investigation using high resolution GPS equipment (*e.g.* Trimble: GeoExplorer with GeoBeacon). To provide an exhaustive set of training data, a subsequent definition of training areas is carried out in a GIS application. This is done by the vegetation experts who performed the collection of training data in the field. According to comparative investigations, this two step process is necessary to achieve high quality classification results and to process independent classifications with distinct training data for smaller sub-regions (McCauley and Engel 1995).

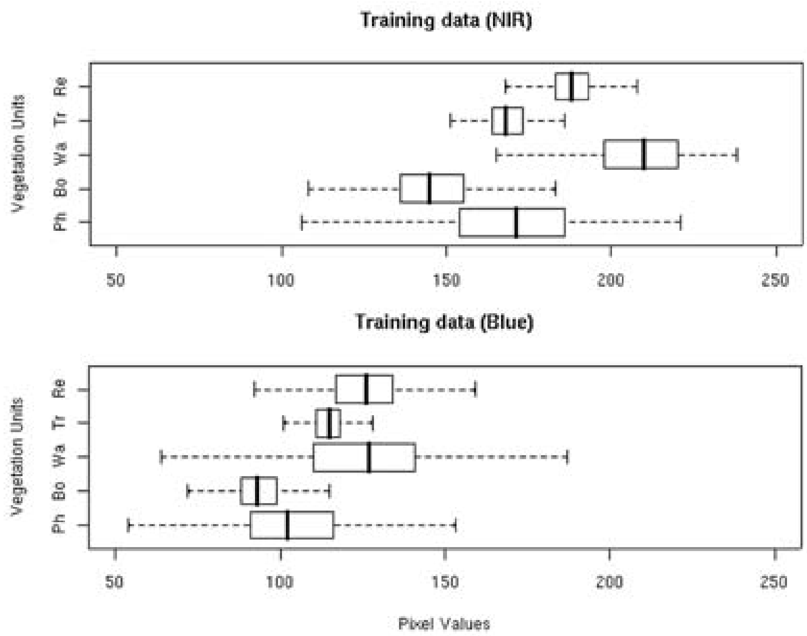

Figure 3: Spectral plots for training data obtained in 2 bands (NIR, B) for 5 vegetation units.

The supervised combined geometric and radiometric classification is carried out using the open source software GRASS (http://grass.osgeo.org). At the beginning of the classification, a cluster analysis of the image data takes place based on the training areas. In practice the spectral and 'artificial' data pre-processed for the classification (*e.g.* G, R, NIR, NDVI, elevation and texture information) are combined in a map group. On the basis of the spectral data characteristics within the training areas, several statistic analyses take place. The results are stored as training signatures in the form of Gaussian mixture distribution and are later used to classify the vegetation units. For parameter estimation, the EM-algorithm is used (Dempster *et al.*, 1977). The number of normal distributions is either statistically specified during the evaluation of the training data using the Rissanen's Minimum Description Length (MDL) criterion (Rissanen, 1983), or can be specified manually in the GIS. Weighting of the normal distributions is carried out next, using *a posteriori* probabilities of the subclasses for creation of the training signatures. For the classification, the 'Sequential Maximum A Posteriori' (SMAP) segmentation algorithm combined with the 'Multiscale Random Field' (MSRF) model is used (Bouman and Shapiro, 1996). The group of layers, previously defined for the cluster analysis, is analyzed using the provided training signatures and assigned to the different vegetation classes (Neteler and Mitasova, 2008). Contrary to pixel-based procedures, a scale-dependant approach is used which uses radiometric and geometric information in the form of neighbourhood relations between pixel values during the class assignment (Ripley, 1996). The MSRF works as an image pyramid with different layers segmented at different image resolutions. Starting from a coarse scaled layer, the probability of affiliation to a class is determined for each pixel within a pre-defined window and passed on to the next, finer scaled, layer (Bouman and Shapiro, 1996).

After the classification, several filter processes take place. A multilevel, raster-based neighbourhood filtering of the results is carried out next. This process minimizes small areas which occur in each classification due to the mixing of pixel and spectral heterogeneity, without manipulating the classification result.

Following this first filter step, the data are converted into a vector shapefile and further processed for the production of the field maps. This entails:

- Reducing the data volume by decreasing vector vertices, without degrading the geometry of the classification substantially.
- Additional filtering of the vegetation geometries on the basis of a project-specific minimum area size. Generally a minimum area of 200 to 500 m² proved to be useful, because smaller areas cannot be represented at 'usual and desired' mapping scales (1:3 000 to 1:5 000). Furthermore, it must be possible to almost exhaustively verify the classification within a justifiable period

of time in the field. For selected vegetation units (*e.g.* types with high protection status, important for nature conservation) the definitions deviate from the general minimum area size specified in the project.

Digital vegetation post-processing (2.4)

After classification and filtering, a complete digital revision of the vector data is essential. This is done by the vegetation experts who were already responsible for working on the training areas in the field.

The steps that follow are: the definition of an optimal mapping scale; the preparation of the field map grids; and the printing of the field maps for verification / mapping.

Verification/Mapping in the field (2.5)

After the classification is filtered and digitally revised, an exhaustive survey of the area under investigation takes place. Under optimal conditions this leads to verification. The focus lies on areas which proved difficult or uncertain during the digital revision. Thus, the effort in the field is strongly reduced and is efficient when compared to conventional mapping methods.

Final digital review and map production (2.6)

After verification/mapping in the field, the results are revised again and finally integrated into the digital field maps (GIS project). The better the quality of the preceding working steps, the smaller the effort required for the final creation of the project maps.

3. Project examples

The method introduced here has been successfully used since 2003. This is documented in four reference projects, which were undertaken on behalf of the Wadden Sea National Park Administrations of Lower Saxony and Schleswig-Holstein as well as the German Federal Institute for Hydrology and Federal Administration of Waterways and Shipping (Table 1).

For the entire terrestrial area of the Wadden Sea National Park of Lower Saxony, a vegetation map of habitat types, supplemented by TMAP units (Trilateral Monitoring and Assessment Program) and biotope types, was established using HRSC-AX and DMC aerial photographs. This project was carried out in order to report on the implementation of the EC Habitats Directive and on the basis of the results of the TMAP working groups (Bakker

Table 1:
Key data of presented reference projects.

Employer	**Wadden Sea National Park Administration of Lower Saxony**	**Wadden Sea National Park Administration of Schleswig-Holstein**	**Federal Institute of Hydrology (BfG)**	**Federal Administration of Waterways and Shipping (WSA)**
Mapping Project	Total terrestrial area of the National Park	Total terrestrial area of the National Park (incl. Halligen)	Elbe from the Wadden Sea up to Hamburg	Weser from the Wadden Sea up to Bremen
Project duration	04.2004 - 01.2006 (21 months)	02.2006 - 12.2008 (ca. 30 months)	08.2007 - 02.2008 (6 months)	06.2008 - 09.2009 (15 months)
Area (ha)	Approx. 33,000	Approx. 15,000	Approx. 10,000	Approx. 8,000
Focus	Dunes, dune slacks, salt marshes, grassland	Salt marshes, (grassland, dunes, dune slacks)	Redbeds, riparian veg. (grassland, salt marshes)	Redbeds, riparian veg. (grassland, salt marshes)
Vegetation typology	TMAP types, Natura 2000 habitat types	TMAP types, plant communities	Plant communities, TMAP and biotop types	Biotop and TMAP types, plant communities
Camera system	HRSC-AX (GSD 32 cm), DMC (24)	UltraCam-D (GSD 10 cm)	DMC (GSD 25 cm)	DMC (GSD 25 cm)
Spectral channels	B, G, R, NIR, PAN (+ Texture)	G, R, NIR (+ Texture)	B, G, R, NIR (+ Texture, laser scan data)	B, G, R, NIR, PAN (+ Texture, laser scan data)
Mapping scale	1:3,000	1:4,400	1:4,300	1:4,300
Field maps (DIN A4)	ca. 1,300	ca. 650	ca. 340	ca. 329
Field work duration	12 weeks (3-4 people)	11 weeks (3 people)	2 weeks (3 people)	6 weeks (1 person)
Team	8 people	8 people	6 people	4 people
Additional service	Natura 2000 conservation status	Agricultural exploitation	Photo documentation	Interpretation

et al,. 2005; Petersen and Lammerts, 2005). The entire area of the National Park (about 33 000 hectares) was mapped using image classification by four vegetation experts. A maximum map scale of 1:3 000 was used (Petersen and Pott, 2005; nature-consult 2006).

Following this project, the entire terrestrial area of the Wadden Sea National Park Schleswig-Holstein was mapped using aerial imagery taken with an UltraCam-D camera. In only 11 weeks of field work, about 15,000 ha of salt marshes, dunes, dune slacks, grassland vegetation, as well as land use and scarps, were mapped (nature-consult ,2008).

On behalf of the German Federal Institute for Hydrology (BfG), reed and adjacent vegetation on both banks of the River Elbe from Otterndorf to Hamburg was mapped. The evaluation used digital DMC aerial imagery and laser scan data together with exhaustive field work. With the described procedure, about 10,000 ha were classified, digitally revised, mapped and verified in the field over a period of only two and a half months (nature-consult, 2007). A similar project (approximately 8,000 ha) was conducted for the Weser River (also the Lesum, Hamme and Wümme rivers) from the Wadden Sea to Bremen for the Federal Administration of Waterways and Shipping (WSA-Bremerhaven, Table 1).

4. Conclusion

The method developed by nature-consult has proven to be successful for large-scale vegetation mapping. With this approach it is possible to efficiently provide high quality, optimized field maps. For example the East Frisian Island Borkum, with a total area of about 3,830 ha, was completely mapped and verified by four field workers in only four days. For this complete survey, 126 analogue field maps (DIN A4) at a scale of 1:3 000 were produced.

As a result, this approach enables the provision of vegetation maps with a very high accurateness of geometrical location and vegetation assignment. Although remote sensing cannot replace field surveys, it can make vegetation mapping more efficient and thus more economical.

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Uncertainty in monitoring salt-marsh accretion on various spatial scales

A.V. de Groot, J.P. Bakker, R.M. Veeneklaas, D.P.J. Kuijper,
Community and Conservation Ecology, University of Groningen,
PO Box 14, 9750 AA Haren, The Netherlands, avdegroot@gmail.com

Abstract

When measuring vertical accretion on salt marshes, one of the concerns is to obtain representative measurements. To gain insight into the spatial uncertainties in marsh accretion, occurring when scaling up small-scale measurements, we analyzed over 10,000 measurements of the thickness of marsh deposits (long-term net accretion) on three barrier-islands. The measurements cover the local scale (< 10 m) as well as the scale of the entire marsh (7 km). We calculated variograms (geostatistics) to determine the variation in accretion on these scales. The results show that because the variance in accretion increases with increasing area of interest, measurements should preferably be evenly distributed over the area of interest.

1. Introduction

Salt marshes on the Wadden Sea islands are dynamic systems that are characterised by a balance between vertical accretion and erosion, and a feedback between vegetation and sedimentation (*e.g.* Doody, 2008). Sedimentation ranges from a few mm to a few cm per year and consists of predominantly fine-grained mineral sediment, largely imported by the flooding waters. The result is a vegetated layer of predominantly silt and clay, typically ranging between 0 – 50 cm, on top of coarser-grained sediment such as sand (Dijkema, 1987). Sedimentation on barrier-island salt marshes is variable over time and exhibits spatial patterns of various sizes, caused by variations in hydrodynamic conditions (*e.g.* storms, seasons), inundation frequency (related to soil elevation) and distance to the intertidal flats and creeks (Allen, 2000; French, 2006).

Knowledge of marsh accretion is important for assessing the development of salt marshes in relation to sea-level rise, but also for nitrogen availability for plants and thus vegetation succession. The presence of variously sized spatial patterns in sedimentation has implications for making reliable predictions of accretion (French *et al.*, 1995; Temmerman *et al.*, 2005). The uncertainty in accretion rates is in the first place given by the measurement error. However, if the measurements are used to represent a certain area, a second component of uncertainty is introduced, namely, the (natural) spatial variation in accretion within that area. We address the question: what are the implications of spatial patterns in accretion for obtaining representative values of marsh accretion? We will apply geostatistics (variograms) to describe the spatial variation in salt-marsh accretion on three barrier islands in the Wadden Sea.

2. Methods and study sites

2.1 Study sites

The main study site is the island of Schiermonnikoog in the Dutch Wadden Sea. The island, 8 km long and 0.5 – 1.5 km wide, features a complex of salt marshes of various ages. The island is used here as a model island for the barrier islands in the Wadden Sea and as a reference site for the nearby Ameland which is affected by gas extraction and subsequent soil subsidence. Part of the measurements were replicated on the salt marshes of Terschelling (NL) and Skallingen (DK).

2.2 Measurements

With a soil corer, the thickness and lithology of the marsh top layer were sampled with a precision of 0.5 cm and an estimated accuracy of about one cm. The top layer is defined as all fine-grained deposits and interspersed sand layers that are situated on top of the sandy subsoil. The thickness of this top layer equals total net accretion since salt-marsh establishment.

The local age of the salt marsh was determined from aerial photographs and historical maps, for Schiermonnikoog given in Kers *et al.* (1998) and for Terschelling and Skallingen derived from Roozen and Westhoff (1985) and Aagaard *et al.* (1995), respectively.

2.3 Measurement layout

The dataset was aggregated from several measurement layouts, some of which were already reported in other publications (*e.g.* Olff *et al.*, 1997; Van Wijnen and Bakker, 2001; Kuijper and Bakker, 2003). The measurements analysed here were taken between 2002 and 2007, amounting

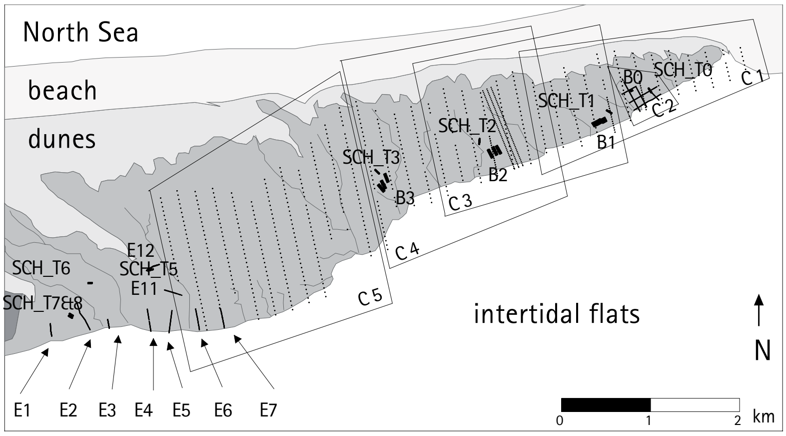

Figure 1: Measurement layout on the main measurement site Schiermonnikoog (NL). The codes represent layouts used for data analysis. C stands for catchment scale, SCH_T for high-middle marsh, B for low-middle marsh and E for salt-marsh edge. The salt marsh roughly increases in age from east (0 years) to west (200 years).

to a total of 10,449 cores on Schiermonnikoog, 967 on Terschelling and 240 on Skallingen. The analysis was carried out on three landscape levels (Figure 1): the entire salt marsh, the catchment scale including several catchments per analysis (C1 – C5; a catchment is the area connected by one creek and its branches) and the sub-catchment scale. On the sub-catchment scale, the salt-marsh edge (E1 – E12), low-middle marsh (B0 – B3) and high-middle marsh (SCH_T0 – SCH_T3 and SCH_T5 – SCH_T8) were studied separately. As the layouts overlapped, some measurements were used in several calculations. On Terschelling and Skallingen, only data from the high-middle marsh were available.

3. Analysis

The data were analysed using variograms, which are a form of geostatistics (*e.g.* Armstrong, 1998). A variogram is a graph that expresses the difference between the values of a measured variable as a function of geographical distance. From a variogram, the size of spatial patterns in the measured variable can be identified. Further, it gives the standard deviation of the variable within this spatial pattern, which is an indication of the uncertainty introduced by scaling up small-scale measurements. Finally, it gives the combination of measurement error and variation on a scale smaller than the measurement spacing.

We calculated variograms using the GIS package Surfer version 8.00. Following Armstrong (1998), outliers were removed and the data were detrended. A side-effect of the detrending is a reduction of the associated standard deviations. Finally, an appropriate variogram model (a standard mathematical function of which several are available) was fitted to each calculated variogram, from which pattern size, standard deviation and small-scale uncertainty could be determined. The fitted model further provides a set of spatial weights used in the interpolation method kriging, which is generally one of the preferred methods for interpolating spatial data.

Aerial view of part of the salt marsh on Schiermonnikoog (NL) in 2006. (Photo: Rijkswaterstaat, www.kustfoto.nl).

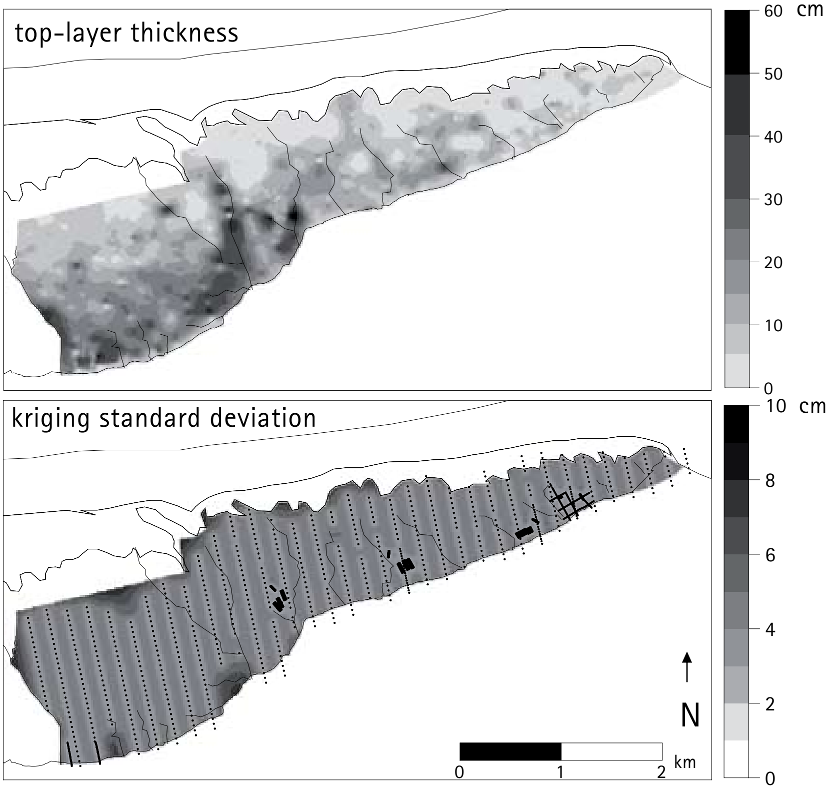

Figure 2:
Upper panel: interpolated top-layer thickness on the salt marsh on Schiermonnikoog using kriging. Lower panel: standard deviations of the interpolated values of top-layer thickness. The dots represent measurements.

4. Results

4.1 Interpolation and prediction uncertainty

For the entire salt marsh of Schiermonnikoog, top-layer thickness was interpolated using kriging with the spatial weights from the calculated variogram (Figure 2). The map shows a general increase in top-layer thickness from east to west and from north to south (upper panel of Figure 2). Thickest layers are found adjacent to the largest creeks, covering only a small part of the total marsh surface. Small dune complexes within the marsh are visible as patches without top layer. Total accretion is mostly between 5 and 20 cm, but values of up to 1 m were sometimes recorded.

The standard deviations of the predicted top-layer thickness, calculated in the kriging procedure, are for the majority of the area 2 – 5 cm (lower panel of Figure 2). The values depend on the values from the variogram and on the density of data points, but (with this method) not on top-layer thickness.

4.2 Spatial uncertainty

For all landscape scales, the patterns in accretion occurring within these areas were identified from variograms. This then gave the standard deviation within these patterns (Table 1). It was necessary to de-trend the data before calculating the variograms, as most are otherwise obscured by a large-scale trend. Consequently, the majority of the standard deviations are reduced by a few percent.

The standard deviations are between 2 and 15 cm (Table 1). In some cases, the spatial pattern could not be captured with the measurement layout so that the standard deviation could not be determined. Within the patterns on the low to high marsh on the sub-catchment scale (codes T and B), standard deviations are in the order of 3 cm. Standard deviations on Terschelling are larger than those associated with similar scales on Schiermonnikoog and Skallingen, even though the de-trending affected the Terschelling data more. Perpendicular to the salt-marsh edge of Schiermonnikoog and within the catchment areas, the standard deviations are also larger. On the scale of the entire marsh and within some catchments, a smaller pattern was found superimposed on a larger one, each with own standard deviation. The standard deviation on the scale of the entire marsh is 6 – 8 cm.

The standard deviation is plotted as function of marsh age in Figure 3 (across the salt-marsh edge is omitted because these transects crossed

Table 1: Uncertainty in measurements of total marsh accretion (top-layer thickness) on several spatial scales, derived from variograms. Locations can be found in Figure 1. Within the groups formed by measurement layouts, the areas are ranked from young to old. In case a second, superimposed pattern was identified, the standard deviations within both patterns are given. SCH stands for Schiermonnikoog, TERS for Terschelling and SKAL for Skallingen.

Location	Year of development	N	Standard deviation (cm)	Measurement error and small-scale variation (cm)
Entire marsh	1913 - present	2184	5.9; 8.0	3.5
Satchment scale				
C1	1985 – present	1123	3.2; 4.7	1.4
C2	1974 – present	1205	3.1	1.7
C3	1964 – 1993	915	6.4	3.7
C4	1964 – 1993	1123	7.4	3.5
C5	1913 – present	1121	7.7; 10.5	3.2
Sub-catchment scale, salt-marsh edge				
E7	1964 – 1993	72	11.8	3.2
E6	1964 – 1993	73	6.9	2.2
E5	1939 – 1993	78	9.7	2.8
E4	1974 – 1993	75	8.9	4.5
E3	1874	62	11.4	3.2
E2	1874 – 1894	108	15.0	3.2
E1	1848 – 1874	86	9.0	4.7
E11	1913 – 1993	55	8.1	8.1
E12	1894 – 1913	578	3.9	2.2
Sub-catchment scale, low-middle salt marsh				
B0	1986	196	2.3	0.6
B1	1980	443	2.0	2.0
B2	1969	554	3.7	3.2
B3	1964	565	2.5	1.7
Sub-catchment scale, high-middle salt marsh				
SCH_T0	1995	602	2.4	1.2
SCH_T1	1984	656	3.5	1.9
SCH_T2	1974	647	2.5	1.4
SCH_T3	1957	639	3.2	1.1
SCH_T5	1900	649	1.8	1.5
SCH_T6	1894	500	-	1.1
SCH_T7&8	1850	987	4.0	2.1
TERS_T1	1925 – 1940	87	5.2	2.7
TERS_T2	1925 – 1940	80	5.8	2.0
TERS_T3	1925 – 1940	400	6.7	1.0
TERS_T4	1920	400	-	3.2
SKAL_T1	1900 – 1930	100	3.3	1.4
SKAL_T2	1900 – 1930	400	2.4	1.7
SKAL_T3	1900 – 1930	100	2.1	1.6

many age boundaries). On the small scale, there is no relation with marsh age. For the catchment scale, the standard deviation increases when the area includes a larger variety of marsh ages. This is related to the general increase in top-layer thickness with increasing marsh age. The same probably holds true for the relatively large standard deviations across the salt-marsh edge.

4.3 Small-scale variation and measurement uncertainty

On the high, middle and low marsh (codes T and B) of all islands there is always small-scale variation plus measurement error (the two cannot be separated with this method). With a measurement spacing that is generally 1 m, it is in the order of 1 – 2 cm which is in line with the initially estimated measurement error. Again, along the salt-marsh edge and on the catchment scale, the values are higher. For the scale of the entire marsh, the value is 3.5 cm.

5. Discussion and conclusions

The standard deviations found from the variograms indicate that if small-scale measurements of net accretion are scaled up, for instance to the catchment scale, the uncertainty in the resulting value is around 3 cm. Values from around the salt-marsh edge should be given an even larger

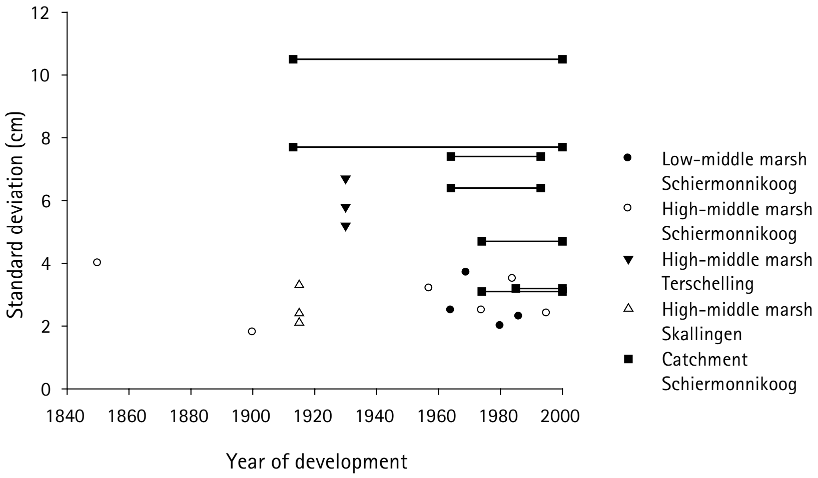

Figure 3: Standard deviation in top-layer thickness (derived from variograms) as a function of salt-marsh age. The symbols represent the various islands and measurement setups. In case the area contains marshes of various ages, this is given as a horizontal line.

uncertainty when scaled up. It should be noted, however, that in the presented calculations, the necessary de-trending removed some of the variation. The uncertainty is therefore somewhat underestimated.

If the area of salt marsh under consideration increases in size, the variation in accretion (given as the standard deviation) roughly increases as well. From the variograms, which were calculated from evenly spaced data whenever possible, the standard deviation of the underlying distribution of accretion could be estimated. Because there is spatial patterning, these standard deviations may already be found within a smaller unit within the area under consideration, but the size of the patterns in generally not known beforehand. Therefore, if part of the area of interest is under-represented in a measurement design, there is a risk of obtaining measurements that are not representative for the area. Accretion measurements from a small scale (*e.g.* heavily clustered measurements within 50 m2 or less) should therefore only be applied with caution to a much larger area (*e.g.* several km^2). Measurement layouts should ideally be suited to the studied spatial scale and processes. This may seem obvious, but often a trade-off has to be made based on costs, effort and accessibility. If possible, measurements should be distributed over the entire area for which a value is desired, so that the chance of sampling all spatial patterns present is largest.

A way to gain insight into the spatial component of accretion uncertainty of measured data is to use kriging for interpolation. The kriging standard deviation gives the uncertainty at unsampled sites (Figure 2). This standard deviation depends on the values from the variogram calculated from the data and the proximity of measurement locations. When determining sediment budgets of salt-marshes, kriging of accretion rates is the preferred method (French *et al.*, 1995).

The results from this paper can directly be applied to accretion rates obtained from dating by, for instance, the radionuclides of ^{137}Cs and ^{210}Pb, or from marker plots, as these all use sediment cores. Uncertainties in short-term accretion rates may differ from those in top-layer thickness, although the first also exhibit spatial patterns that can be described with variograms (French *et al.*, 1995 and Van Proosdij *et al.*, 2006). The ambient driving forces and conditions will be more pronounced in short-term accretion rates than in top-layer thickness, which is the accumulated outcome of all past conditions.

A study is underway in which the uncertainties described in this paper will be compared to the sizes of patterns in which they occur, and will be related to marsh age and driving factors such as elevation.

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Remote sensing of the Wadden Sea – a tool supporting TMAP and WFD monitoring

Kerstin Stelzer, Brockmann Consult,kerstin.stelzer@brockmann-consult.de
Carsten Brockmann, Brockmann Consult, carsten.brockmann@brockmann-consult.de
Jasmin Geißler, Brockmann Consult, jasmin.geissler@brockmann-consult.de

Abstract

Monitoring of the Wadden Sea – during low and high tides – is subject to the EU Water Framework Directive, the Fauna Flora Habitat Directive, the Birds Directive, and the Trilateral Monitoring and Assessment Programme at European Level. Sediment type, vegetation cover and mussel beds are important parameters, directly or indirectly required by these directives and programmes, respectively. These are parameters that can be mapped from airborne and space optical remote sensing data during low tide, while during high tide the sediment concentration, transparency and chlorophyll-a concentration in the water column can be retrieved from spaceborne measurements.

Research and development have been taking place for several years and have always been made with close involvement of the Wadden Sea Secretariat, the National Park Authorities and the regional environmental agencies. The techniques used in the framework of operational monitoring activities are currently evaluated by the users themselves. The classification result is basic information that serves equally the monitoring requirements for TMAP, WFD and Natura 2000.

The advantage of the developed methods are a large scale synoptic overview and an automated processing, almost independent from manual interaction which provides repeatable and consistent classification results, suitable for time series analysis and change detection.

The disadvantage of the multi-spectral data currently in use is the coarse spatial resolution (30m) and the poor temporal availability of useful datasets. The low repeat cycle of the satellite in combination with the requirement for low tide and cloud-free observation conditions limit the number to very few images per year. Therefore, an R&D project[1] was launched in February 2008 which aims to utilise spaceborne SAR data, optical data and background knowledge which can be obtained under all weather conditions.

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1. Introduction

Techniques for classification of remote sensing data of intertidal flats have been developed over the past 8 years in national and international projects, namely the EU projects BIOPTIS (1998-2001) and HIMOM (2001-2004), the national projects OFEW (2005-2007) and DeMarine Environment (TP-4, running since 2008). Remote sensing of water constituents is a technique that has become mature and operational during the past 10 years. The close interaction with the users in all projects enables the development of products and services that serves the requirements of the users, especially in respect of the reporting duties for TMAP, WFD and Natura 2000. Users are involved in the product specification as well as in the validation and assessment of the quality of the products and services.

The challenges of remote sensing of intertidal flats are the strong influence of the water coverage on the spectral signal (1), spectral similarity of different vegetation types (*e.g.* seagrass and green algae) (2), coarse spatial resolution of the sensors (3) with sufficient spectral resolution and, last but not least, the low data availability due to low tide constraints and cloud conditions (4).

The challenges of remote sensing techniques of coastal waters are also covered by a number of past and running projects. Here, atmospheric correction is a critical issue, because over 90% of the measured signal relates to the atmosphere, the remaining 10% carries information about the water column. In coastal areas factors like bottom reflectance or stray light coming from the coast can also affect the measured signal at the satellite sensor.

In the following sections the focus is laid on the classification of intertidal flats.

2. Data and Methods

Data from different sensors with focus on Landsat, ASTER and SPOT images have been used for the classification of intertidal flats. The time series of Landsat images starts in 1989, the availability is on average one image per year.

Surface types have characteristic spectral

Figure 1: Colour of intertidal flats (left) and true colour image of the Hallig Waddensea at the coast of Schleswig-Holstein (right), Satellite Data Source: Landsat 5 TM (c) Eurimage 2006, (Photos: K. Eskildsen).

reflectances in the visible, near infrared and short-wave infrared parts of the electromagnetic light spectrum. Remote sensing instruments measure these different bands or channels of the spectrum to build up a picture of characteristic information of surface types. The different sensors available are characterised by their number and position within the spectral bands (spectral resolution), the size of the pixels (spatial resolution), the area covered (swath width), as well as the repetition time in which one area is acquired twice (temporal resolution). Not all available sensors are suitable for use on intertidal flats because they have difficulty differentiating between some of the very special conditions on the flats (*e.g.* water coverage, dark surfaces).

Figure 2 shows some characteristic spectral reflectances of different surface types in the full range of the measured spectrum. The blue box indicates the visible part of the light. However, vegetation and water coverage show up particularly strongly in the near infrared and shortwave infrared bands. The spectral information forms the basis for the classification methods applied to optical remote sensing data.

A standardised method has been developed in a series of international and national research projects dealing with the classification of intertidal flat surfaces. This method is based on a linear spectral unmixing, which divides the measured reflectance spectra into "pure" surface types which are inside of one pixel. Further, different indices are calculated from band combinations. These parameters are further processed in a decision tree in order to assign each pixel to a specific surface type class. Before applying this classification, pre-processing is necessary. This includes an atmospheric correction, georeferencing, and masking of the intertidal flat areas. Surfaces that can be spectrally distinguished are different sedi-

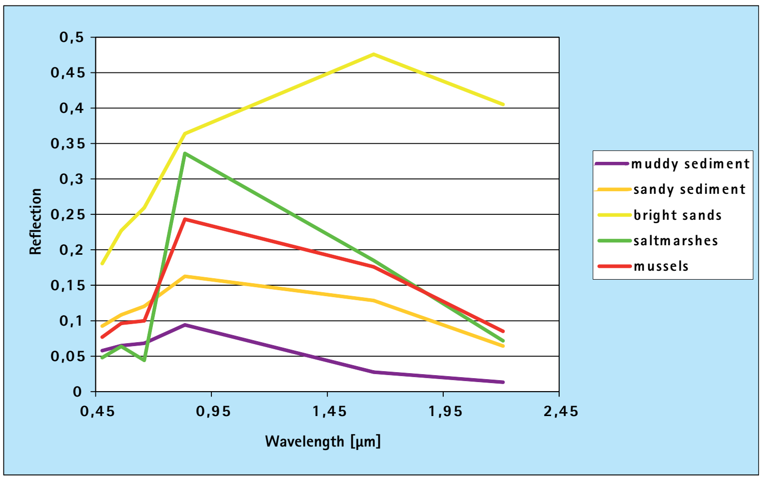


Figure 2: Spectral reflectances of different surface types of the Wadden Sea. The visible part of the light extends from 0.3 to 0.75 of the electromagnetic spectrum.

ment types (water covered and dry), mussel beds, macrophytes and diatoms.

The current project DeMarine Environment (subproject intertidal flats) sets out to combine the information derived from optical remote sensing data with information from radar data and **in situ** knowledge.

The radar data provide information about the surface roughness that is typical for different surface types, such as mussel or oyster beds or ripples in sandy sediments (Gade **et al.**, 2008). Further, information from the long-term monitoring is used to draw up maps indicating the probability of occurrence of dedicated surfaces types (*e.g.* seagrass occurrence [Reise and Kohlus, 2008] or mussel beds). **In situ** measurements are taken according to a protocol for remote sensing data which ensures a proper validation of the results. This includes the mapping of the sediment colour, the coverage with mussels and macrofauna or diatoms, the roughness of the surface (ripple height and direction) and the situation of the water coverage.

A habitat knowledge base has been defined which collects sedimentological and biological parameters, optical characteristics and spatial structure patterns in a structured way. This knowledge base will provide important input for an integrated classification method to be developed during the next year's work.

Validation is performed by comparing the classification results with available **in situ** data from the regular monitoring programmes and additional investigations.

3. Results

The results of the classification provide pixel-based information about the surface type of all - intertidal flat not covered by water. There are five different sediment classes ranging from sandy to muddy sediments, two classes for vegetation (different densities), one class for mussel beds and one class for beaches / bright sands. Figure 3 shows one of the classification results for the German Wadden Sea area.

A time series of Landsat images has been classified in the framework of the national project OFEW. Here, the standardised classification method has been applied to a time series of Landsat images covering nine years. On a test base, the method has

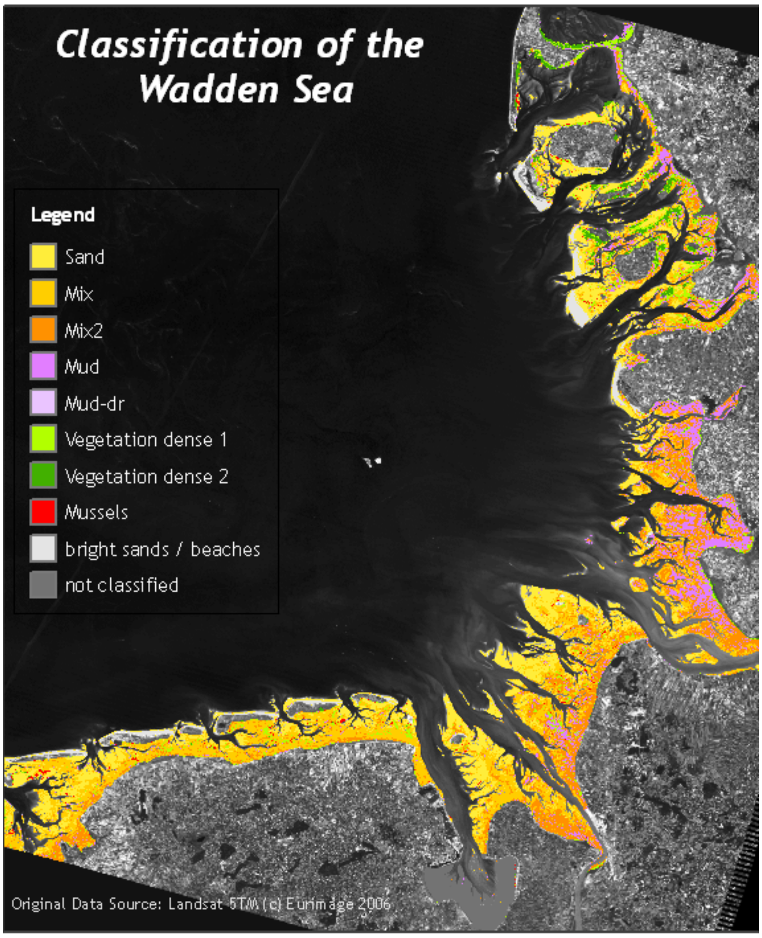


Figure 3: Classification result of the German Wadden Sea, Landsat image 18.07.2008.

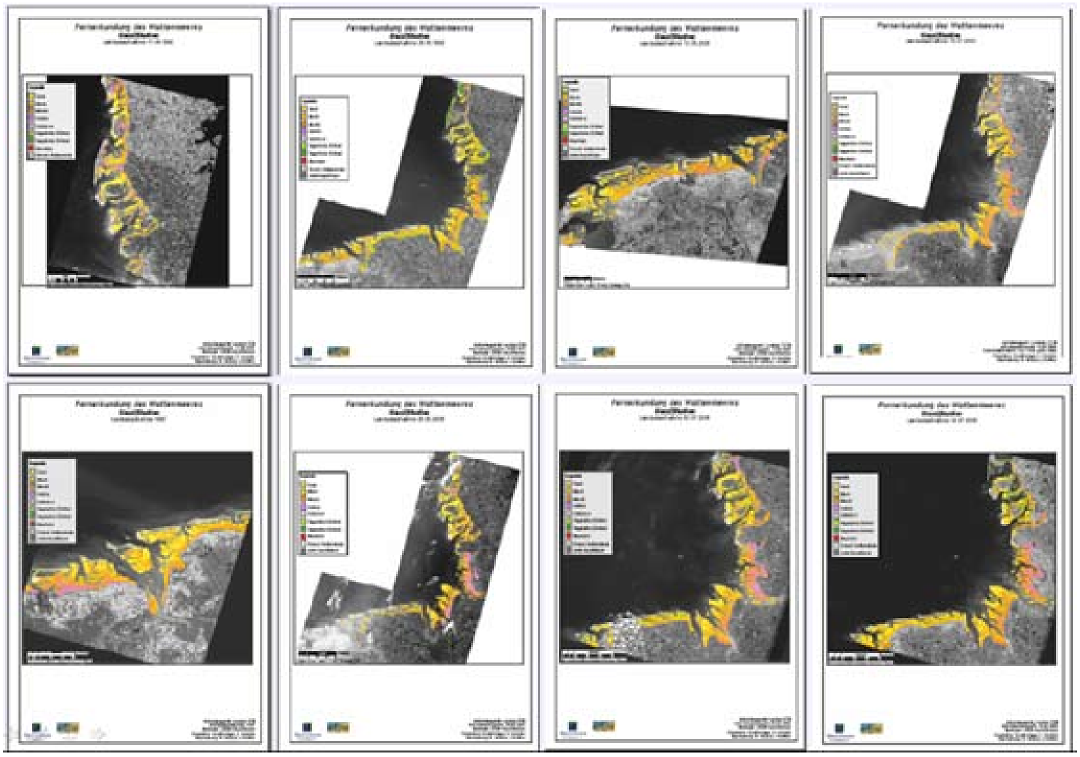


Figure 4: Examples of classified Landsat images (OFEW project).

been applied also to SPOT and ASTER data. It could be demonstrated that the method is transferable to other acquisition dates as well as to other sensors with comparable band settings.

With support of the Common Wadden Sea Secretariat, the classification method has been applied to a trilateral data set, compiled from three different Landsat scenes. This gives the opportunity to retrieve an area-wide assessment of the sediment.

The classification results have been validated with **in situ** data available from the operational monitoring programmes. The comparison with the seagrass monitoring of the respective years shows comparable results in seagrass coverage. The example below shows the area derived from the three overflights in 2006 ("Monitoring" pillars) with the area derived from two satellite overpasses in the same year. However, in the clas-

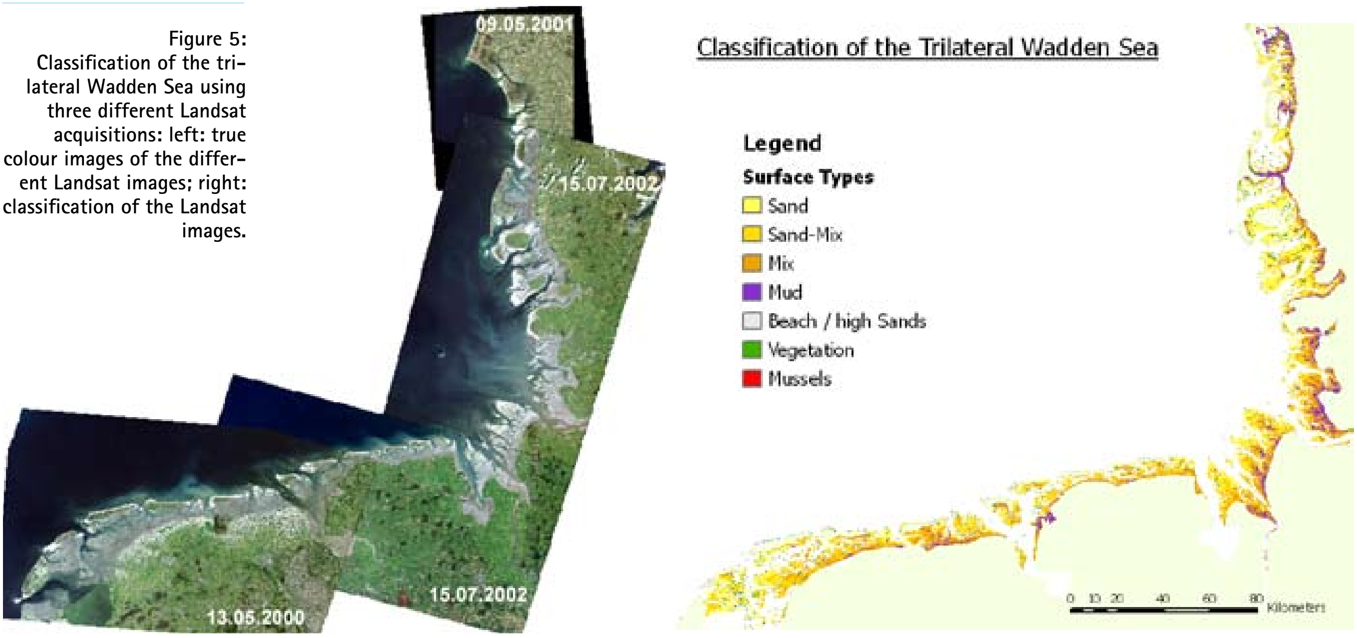
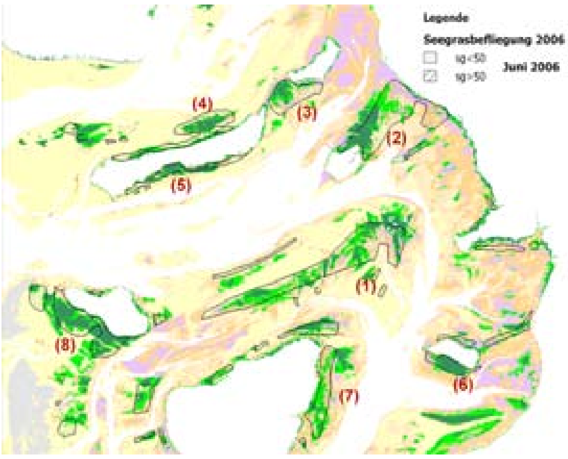


Figure 5: Classification of the trilateral Wadden Sea using three different Landsat acquisitions: left: true colour images of the different Landsat images; right: classification of the Landsat images.



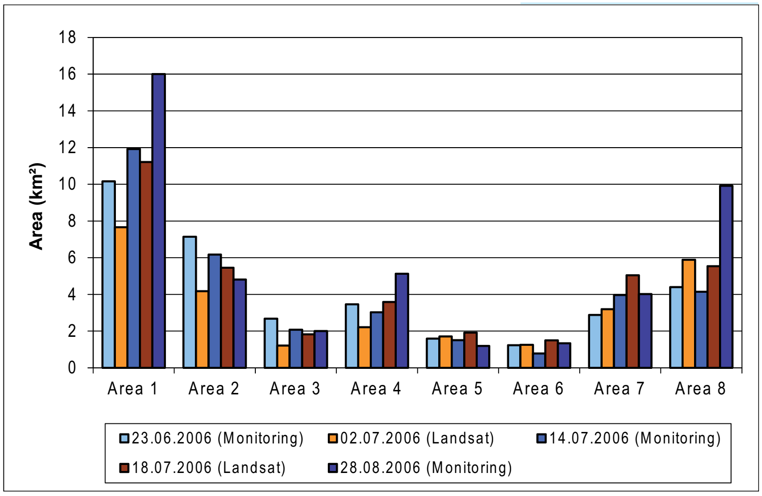


Figure 6: Right: Area covered by seagrass for defined seagrass meadows (left: map with area numbers). Red: remote sensing data, blue: in situ data.

sification results, green algae are also included in the vegetation class. This has to be taken into account when looking at the results. In the currently conducted project. This aspect will be covered by integrating the stability of seagrass occurrence into the classification system.

Another example for validation is the comparison of sediment classes with **in situ** measurements along a transect on Blauortsand in Schleswig-Holstein (data source: Reimers, 2005). Most of the sediment classes are confirmed by **in situ** measurements and expert knowledge (Reimers, 2003 and personal comments), although the two dates of acquisition differ by almost two years.

The overall assessment of the results is generally promising, but not yet fully sufficient for monitoring purposes. Therefore we continue our activities within running projects by enlarging the input sources for the classification system.

4. Outlook

Within the DeMarine project that was started in early 2008, different data sources are combined in order to improve the accuracy of the classification, enlarge the number of different surface types that can be classified and therefore retrieve more reliable and requested results.

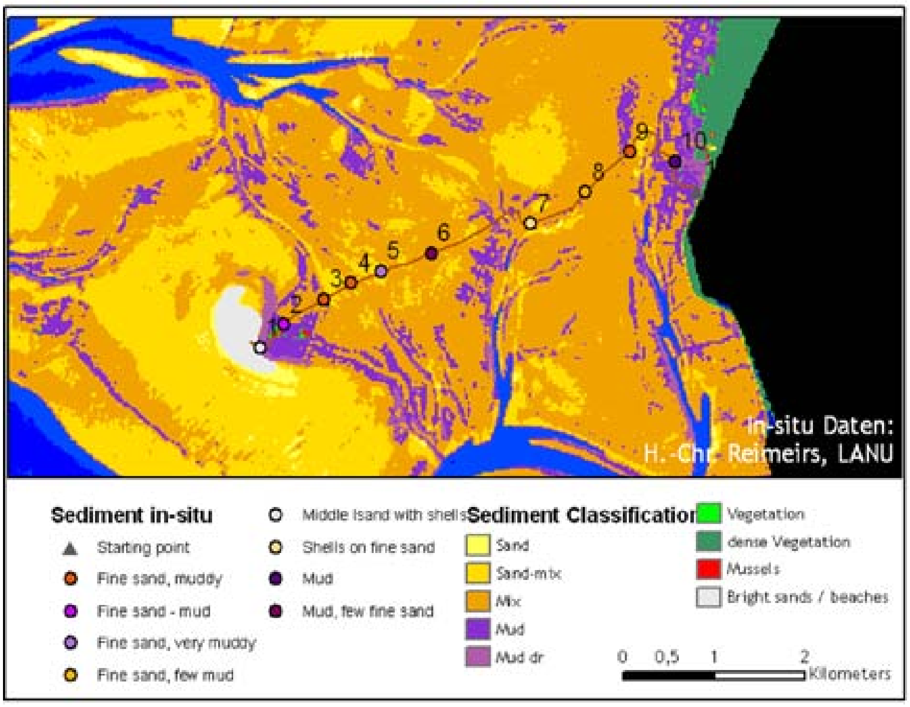


Figure 7: Comparison of sediment classes and in situ measurements, SPOT-5 image from 27.07.2008 and in situ data from 16.09.2006 (courtesy H-C Reimers, LANU).

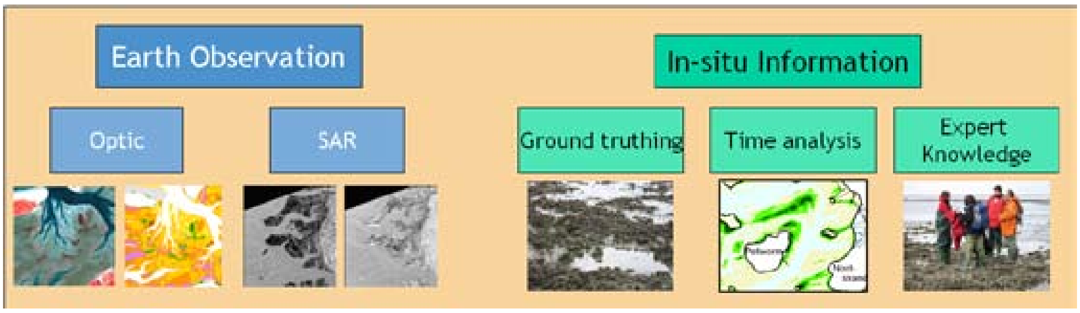


Figure 8: Input data for upcoming classification system combining different information sources in the framework of DeMarine Environment (TP-4).

Further, there are and will be more satellite missions in the near future with promising features of sensors such as higher spatial and temporal resolution. We will investigate how these sensors might be integrated into our systems and which improvements can be reached. It is particularly important that the operational monitoring system yields reliable and stable data sources and, consequently, results. Remote sensing can provide information on a spatial scale which cannot be reached by **in situ** measurements and therefore provides complementary information to the current monitoring systems.

We recommend that we continue to follow remote sensing developments with a view to integrating any worthwhile statistical platforms and data into the monitoring program for the intertidal flats of the Wadden Sea.

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Monitoring for the Habitats Directive and the importance of terrestrial invertebrates

Oliver-D. Finch, oliver.d.finch@uni-oldenburg.de
Rolf Niedringhaus, rolf.niedringhaus@uni-oldenburg.de
Carl-von-Ossietzky University of Oldenburg, Faculty V, Institute of Biology and Environmental Sciences, D-26111 Oldenburg, Germany

Abstract

There are various attempts to monitor and assess the ecological status of habitats. Within the Habitats Directive (HD), individual sites that are part of the Natura 2000 network (N2000) have to be inventoried to assess their conservation status. In the Wadden Sea area, terrestrial N2000 sites are mainly beaches and dunes as well as salt marshes. Monitoring according to the HD has to be targeted 1) to analyse the conservation status and 2) has to evaluate the impact of management measures on the conservation status of the natural habitat types listed in Annex I and of the species listed in Annex II of the HD. We analysed the TMAP monitoring approach practised in the Wadden Sea to assess "Typical Species", a criterion demanded within HD monitoring. Deficits in TMAP occur mainly within the species-rich communities of invertebrates, which can act as important indicators of biodiversity and habitat status. Including further animal indicator groups in the monitoring work is promising and practicable, for example, in "TMAP selected sites" where only vegetation is currently mapped. When invertebrates are included, the quality of site monitoring for HD purposes can be improved.

1. Introduction

The Habitats Directive (HD) (Council Directive 92/43/EEC) and the subsequently established network of the Natura 2000 (N2000) sites is one of the most important strategic and applied tools to maintain biodiversity at the European level. Sites with a high biodiversity value should be protected and maintained by the member states. Thus, the HD is one of the most positive means of achieving International biodiversity commitments, such as the Convention on Biological Diversity (CBD) (*e.g.* Cantarello and Newton, 2008).

Terrestrial habitat types in the Wadden Sea Area that are listed in the N2000 are mainly beaches and dunes as well as salt marshes. Overall, terrestrial sites occupy only a small area of the Wadden Sea. For example, in the Wadden Sea National Park of Lower Saxony, they comprise only 7% of the total area (2,777 km^2). However, they harbour a huge species richness (*e.g.* Niedringhaus *et al.*, 2008a). At least twelve different terrestrial habitat types can be distinguished and are protected within the N2000 in individual sites in the Wadden Sea Area. According to the HD, these sites should be periodically monitored to ensure a favourable conservation status. This monitoring according to the HD has to be targeted 1) to analyse the conservation status (Article 11 of the HD) and 2) has to include an evaluation of the impact of management measures on the conservation status of the natural habitat types of Annex I and the species in Annex II (Article 17 of the HD).

The Wadden Sea Area reports for HD monitoring include main results of the well established TMAP-monitoring. For example, within the TMAP monitoring of dunes (including beaches) is carried out every five years to assess changes in dune location, areas of different dune types and natural dune succession, while taking into account climate change, coastal protection measures, and human impacts (*e.g.* from tourism, eutrophication) (TMAP Common Package of monitoring parameters) (www.waddensea-secretariat.org). Additionally, a detailed monitoring at selected sites is practised with regard to the HD.

We examined the TMAP monitoring that is actually practised in terrestrial sites of the Wadden Sea Area to asses its transferability to HD monitoring. However, no common standard for implementing HD monitoring within the EU has yet been created (Cantarello and Newton, 2008). Thus, our study gives a feedback on the further development of both, TMAP and HD monitoring.

2. Results and discussion

Detailed monitoring at selected sites within the TMAP program aims to assess structure and function of species and communities according to the HD. However, currently, only parameters of vegetation are inventoried (www.waddensea-secretariat.org):

- TMAP vegetation types (area and location) (ha, GIS polygon);
- Species composition of plants: abundance of species per m²;
- Selected typical plant species: abundance per m²;
- Lichen cover in grey dunes (%) (Denmark only).

Apart from birds (which are included in other parts of the TMAP), no other characteristic or typical animals are included in this comprehensive monitoring of terrestrial habitats. Thus, this procedure seems to be inadequate with regard to the general aim as stated above.

HD-relevant habitat types in the terrestrial sites of the Wadden Sea are mainly present within beaches and dunes and in the salt marshes (Table 1). For these sites, monitoring requires continuous surveillance of the conservation status of the natural habitats and species (Article 11). It must evaluate how measures taken within the HD (Article 17) (Council Directive 92/43/EEC) impact on the conservation status of the natural habitat types and species of Community interest. Article 1 defines the measures ("measures required to maintain or restore the natural habitats and the populations of species of wild fauna and flora at a favourable status") and Article 1e explicitly adds that in terms of "populations of species of wild fauna and flora" typical species are included. Thus we are convinced that monitoring of characteristic/typical species for the HD should include invertebrates as well as plants and birds because they are indicator species for the protected habitats. Such species provide complementary information for assessment under both Article 11 and Article 17

As currently no monitoring of invertebrate animals in the terrestrial habitats of the Wadden Sea Area is practised, almost nothing is known about trends and effects on populations and communities of (typical) invertebrates due either to natural changes like succession or of effects of HD-directed measures (like *e.g.* sod-cutting, mowing or grazing, de-embankment of polders) and other conservation efforts. However, as reported by the TMAP Ad-hoc working group Beaches and Dunes (2006: 8), "monitoring activities must be directed more explicitly to obtain information about the presence of the whole range of characteristic species and communities as required by the Habitats Directive". This implies that beside plants and birds, other characteristic species should be monitored.

In the HD relevant habitat types, invertebrates are main contributors to the overall high species richness. For example, in Lower Saxony, up to 2,000 species of a few selected taxa occur in eleven habitat types (Figure 1). Many of them are species highly adapted to specific microhabitats, (dynamic) structures and specific food plants. They are typical species in the context of the HD and often listed in the Red Lists of endangered species (Table 2).

Generally, for HD monitoring, typical species and methods for their assessment can be derived from expert opinion, general national surveys, site-based sampling or re-use of information from red lists work (European Commission, 2006). Various lists of potential indicator taxa, typical species, and methods to evaluate them have already been published. For example, at German national level, standards are set out for assessments during conservation planning and for impact regulation under the nature protection law (*e.g.* Trautner. 1992; Schlumprecht, 1999; Bernotat *et al.*, 2002). Such

Table 1: Terrestrial HD habitat types in the Wadden Sea area

Salt marshes	
1330	Atlantic salt meadows (Glauco-Puccinellietalia maritimae)
Beaches and dunes	
2110	Embryonic shifting dunes
2120	Shifting dunes along the shoreline with *Ammophila arenaria* ("white dunes")
2130	Fixed dunes with herbaceous vegetation ("grey dunes")
2140	Decalcified dunes with *Empetrum nigrum* (brown dunes)
2150	Atlantic decalcified fixed dunes (Calluno-Ulicetea)
2160	Dunes with *Hippophae rhamnoides*
2170	Dunes with *Salix repens* ssp *argentea* (Salicion arenariae)
2180	Wooded dunes of the Atlantic, Continental and Boreal regions
2190/2191	Humid dune slacks and stagnant waters
Further (only locally)	Habitat code: 3130, 4010, 4030, 7140, 9100, 9190

	Araneae	Ensifera & Caelifera	Macro-lepidoptera	Carabidae	Hymenoptera (Aculeata only)	Others (leafhoppers, freshwater taxa, ...)
RL 0-3	65	4	121	67	50	...
Total	264	17	376	214	345	> 5,000
% endangered	24,6	23,5	32,2	31,3	14,5	...

Table 2: Endangered species of selected taxa of invertebrates and total species number in the Wadden Sea National Park of Lower Saxony (RL = Status in the Red Lists; data from Niedringhaus et al., 2008a).

lists were even published in the context of the HD (Ssymank *et al.*, 1998; Fartmann *et al.*, 2001). To conclude, the selection of typical species can be based on a best expert opinion and should be done at regional or national level. "Typical species suitable for HD monitoring may include all species groups, for example, plants, lichens, mosses as well as all animal groups including birds and species (groups) not listed in the annexes of the Habitats Directive" (European Commission, 2006: 28).

Several assessment criteria can be proposed for monitoring. A first selection may include:

- Ratio of threatened species to all species;
- Ratio of typical to non-typical species;
- Ratio of specialists to exotics;
- Occurrence/ratio of various ecological guilds/taxa;
- Habitat requirements and stenotopy of species;
- Spatial and functional connectivity of species.

3. Conclusions

Typical species and indicator groups of invertebrates can be used for integrated monitoring, if HD habitat types and other habitats of conservation concern are to be investigated at the scale of individual sites and if changes in communities due to succession, land use changes and HD-driven measures are to be documented. The suitability of the indicator taxa approach has already been documented in the Wadden Sea Area, for example, recently during a salt marsh recreation project (Niedringhaus *et al.*, 2008b). We suggest, that typical species and indicator groups of invertebrates can be relatively easily included in the permanent monitoring plots of the TMAP monitoring. This would ensure monitoring at habitat-level to evaluate favourable conservation status (Article 11 of the HD). Furthermore, characteristic/typical species and communities of invertebrates should be included in the evaluation of HD-directed measures in the (terrestrial) habitats of the national parks. This would be of value to the monitoring of management plans (Article 17 of the HD).

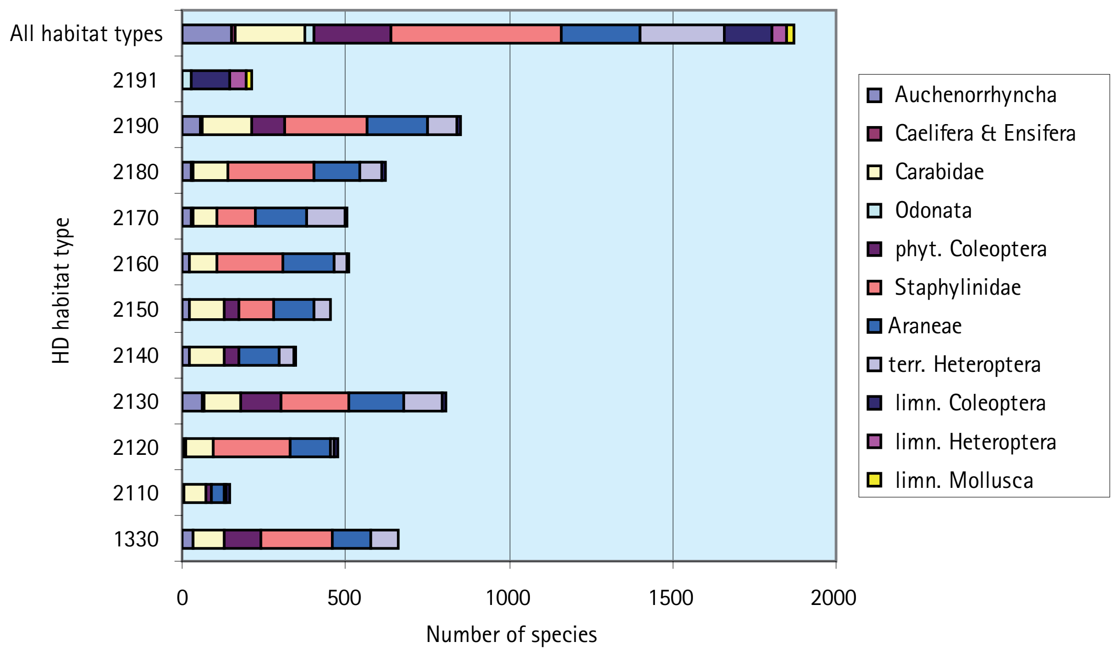

Figure 1: Species numbers of selected taxa of invertebrates in HD habitat types of the Wadden Sea National Park of Lower Saxony (data from Niedringhaus *et al.*, 2008a).

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Figure 2: Fine scaled habitat complexes with natural dynamics guarantee a high species richness of invertebrates in grey dunes (Norderney, May 2009) (Foto: Niedringhaus).

Winter temperature is more important than summer chlorophyll concentrations for macrozoobenthos dynamics in the southern Wadden Sea

Jan Drent, NIOZ Texel, jan.drent@nioz.nl

1. Introduction

Eutrophication is an important anthropogenic impact in marine ecosystems bordering areas with large human populations worldwide (Cloern, 2001). The Wadden Sea is influenced by eutrophication. Nutrient loads have increased during the second half of the twentieth century (Van Raaphorst and De Jonge *et al.*, 2004). This has resulted in an increased primary production and a higher biomass of phytoplankton and microphytobenthos (Cadee and Hegeman, 2002, 1984). It was estimated that primary production increased five fold since pre industrial times (Van Beusekom, 2005).

In shallow systems like the Wadden Sea, the macrozoobenthos is an important consumer of primary produced material. The macrozoobenthos is likely to respond to an increased food supply due to eutrophication. Indeed a strong positive relationship between primary production and biomass of the macrozoobenthos was found in a cross system comparison (Herman *et al.*, 1999). In line with this, the biomass of the macrozoobenthos in the western Dutch Wadden Sea increased following the elevated primary production and biomass of the phytoplankton (Beukema, 1991; Beukema *et al.*, 2002). However this pattern is not consistent over the entire Wadden Sea (De Jonge and Essink, 1991; Essink *et al.*, 1998, Van Beusekom *et al.*, 2001).

In search of general patterns, the regional differences in eutrophication and the response of the macrozoobenthos in the southern Wadden Sea are further analysed in this paper. Starting point is the Pearson-Rosenberg model (Pearson and Rosenberg, 1978; see *e.g.* Heip, 1995, for a generalized concept) where the response of the macrozoobenthic community is described in terms of biomass, abundance and diversity. With increasing organic loads due to eutrophication, these terms first increase and at even higher loads decline again. Under the relatively mild eutrophication effects in the Wadden Sea we would expect an increasing biomass abundance and diversity and declining evenness of the macrozoobenthos with increasing organic load. The reverse is expected at declining organic loads. Time series of chlorophyll-a concentration as a measure of organic load and abundance, biomass, diversity and evenness of the macrozoobenthos were analyzed for long term trends. In addition, time series models were used to relate changes between years in the macrozoobenthos time series with chlorophyll-a concentrations and winter temperature.

Winter temperature has been identified as an important factor influencing dynamics of the macrozoobenthos (Beukema, 1990, 1992) and may obscure effects of organic load (Essink *et al.*, 1998). Winter temperature effects can be divided into effects on winter mortality and on recruitment, the last specifically for bivalves. To account for these two effects, changes in the macrozoobenthos were related to winter temperature and also to winter temperature of the previous winter. Macrozoobenthos samples were taken in late winter to early spring, when winter mortality has taken place already and recruitment has yet to occur. The effects of recruitment will only become apparent in the next sampling event a year later and thus can be taken into account by looking at the effect of the previous winter. Results of the analysis indicate very little effect of chlorophyll-a concentration on the macrozoobenthos metrics studied in contrast to the effects of winter temperature.

2. Material and methods

2.1 Data

For this paper, data were used that were compiled earlier for the Quality Status Report 2009 Thematic Reports on eutrophication (Van Beusekom *et al.*, 2009) and macrozoobenthos (Van der Graaf *et al.*, 2009). Parallel time series on chlorophyll-a concentrations in the water and on macrozoobenthos of the intertidal flats were available from three areas in the southern Wadden Sea (The Netherlands and Lower Saxony): (1) The western Dutch Wadden Sea, (2) the eastern Dutch Wadden Sea and (3) Norderney. Information on chlorophyll-a concentrations in the Dutch Wadden Sea was taken form the DONAR data base (www.waterbase.nl). For the western Dutch Wadden Sea the stations Doove Balg West, Marsdiep Noord and Vliestroom were selected, in the eastern Dutch Wadden Sea data from stations Dantziggat, Zoutkamperlaag zeegat and Zuid Oost Lauwers oost were used. At Norderney, chlorophyll-a measurements were made available by the Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz. Yearly mean chlorophyll-a concentrations were calculated by averaging values over the period May-September. This measure is a good proxy for the eutrophication status of the Wadden Sea (Van Beusekom, 2005). Chlorophyll-a levels years were characterized by the average chlorophyll-a levels over the period May-September (Van Beusekom *et al.*, 2009).

Macrozoobenthos in the Western Dutch Wadden Sea is being monitored on the Balgzand intertidal flats at 12 transects and 3 permanent stations since 1970 (Beukema *et al.*, 2002). Two transects in the very high intertidal zone (1 and 2 in Figure 1 in Beukema *et al.*, 2002) and one transect and one permanent station on the border between intertidal and subtidal (12 and A in Figure 1 in Beukema et al. 2002) were excluded from the analyses, because these habitats are not represented in the sampling of the other two areas. In the eastern Dutch Wadden Sea, comparable macrozoobenthos data from 1988 onwards are available from three transects on the Piet Scheveplaat (Dekker and Waasdorp, 2007) and five permanent sampling stations at the Groninger Wad (Essink 1978). At Norderney, sampling of macrozoobenthos has been done since 1976 at four stations (Dörjes et al. 1986). Data from sampling in late winter or early spring were used to calculate abundance, biomass, diversity and evenness. Abundance is the total number of individuals of all macrozoobenthic taxa per m^{-2}. Biomass is the summed ash-free dry mass of all the macrozoobenthic taxa per m^{-2}. Diversity is the Simpson's diversity D, expressed as 1-D. Evenness $E_{1/D}$ was calculated by dividing the reciprocal of D with the number of species in the sample (Magurran, 2004).

Mean winter temperature data used are the three month average surface water temperatures (December through February) obtained from the Marsdiep tidal inlet in the Western Dutch Wadden Sea (see Van Aken 2008 for details). It was assumed that these temperature data are representative for the winter character over the entire southern Wadden Sea area.

2.2 Analysis

Time series were tested for monotonic trends with a Mann-Kendall trend test.

Simple linear and non-linear time-series models were used to look for relationships between the macrozoobenthos and explanatory variables chlorophyll-a and winter temperature. Details about the models are described in Van der Meer et al. (2000). In short, the rate of change R_x of biomass (R_{bio}), density (R_{den}) and diversity (R_{div}) were calculated as the $\log(N_{t+1}/N_t)$ where N_t is the macrozoobenthos value at time t. R_x was related to the log of the macrozoobentos value and exogenous variables in a linear model and also in two non-linear models, the Ricker model (Ricker, 1954) and Royama model (Royama 1992). The main difference between the models is the shape of the function relating R_x to N_t.

Mallow's Cp statistic was used for model selection (Wetherill, 1986). The models with the lowest Cp were considered to be the most parsimonious description of the data. All analyses were done with the statistical package R version 2.7.1 (R development core team 2008).

3. Results

3.1 Trends in time series

Summer chlorophyll-a concentrations in the western Dutch Wadden Sea overall declined during the period form 1976 to 2008 with values peaking above 20 mg m-3 in the middle of the eighties declining to below 10 mg m-3 during the last five years (Figure 1A, Table 1). In the eastern Dutch Wadden Sea the summer chlorophyll-a concentrations fluctuated around 20 mg m^{-3} without a trend (Fig. 1B, Table 1). At Norderney, summer chlorophyll-a concentrations more than halved from around 20 mg m^{-3} at the start of the series in 1985 to less than 10 mg m^{-3} during the last four years (2003-2006) (Fig. 1C, Table 1). Winter sea water temperature in the Marsdiep inlet showed an increasing trend between 1970 and 2008 (Mann Kendall Tau=0.261, P=0.02; Fig. 1A).

Between 1970 and 2008 the abundance of individuals of macrozoobenthic taxa increased in the western Dutch Wadden Sea (Fig. 1D, Table 1). However, during the period from 1976 until 2008 when chlorophyll-a data are available there is no significant trend in macrozoobenthos abundance (Table 1). In the eastern Dutch Wadden Sea and at Norderney there are also no trends in abundance (Fig. 1E and F, Table 1).

Table 1:
Results of Mann Kendall tests for monotonic trends in time series of summer chlorophyll-a concentrations and macrozoobenthos measures biomass (g m^{-2}), abundance (n m^{-2}), diversity (1-D) and evenness ($E_{1/D}$) in late winter/early spring in three areas, Western Dutch Wadden Sea (WDWS), Eastern Dutch Wadden Sea (EDWS) and Norderney (NN).

		Chla		Biomass		Abundance		Diversity		Evenness	
Area	Period	Tau	P	Tau	P	Tau	P	Tau	P	Tau	P
WDWS	1970-2008	-	-	0.521	<0.001	0.239	0.03	0.068	0.55	-0.421	<0.001
	1976-2008	-0.386	0.002	0.461	<0.001	0.068	0.59	0.072	0.57	-0.397	<0.001
EDWS	1982-2007	0.022	0.90	-	-	-	-	-	-	-	-
	1988-2007	-0.018	0.94	0.232	0.16	0.082	0.63	-0.042	0.82	-0.074	0.67
NN	1976-2006	-	-	0.269	0.04	0.006	0.97	0.082	0.53	-0.265	0.04
	1985-2006	-0.377	0.02	0.247	0.11	0.039	0.82	0.260	0.10	-0.304	0.06

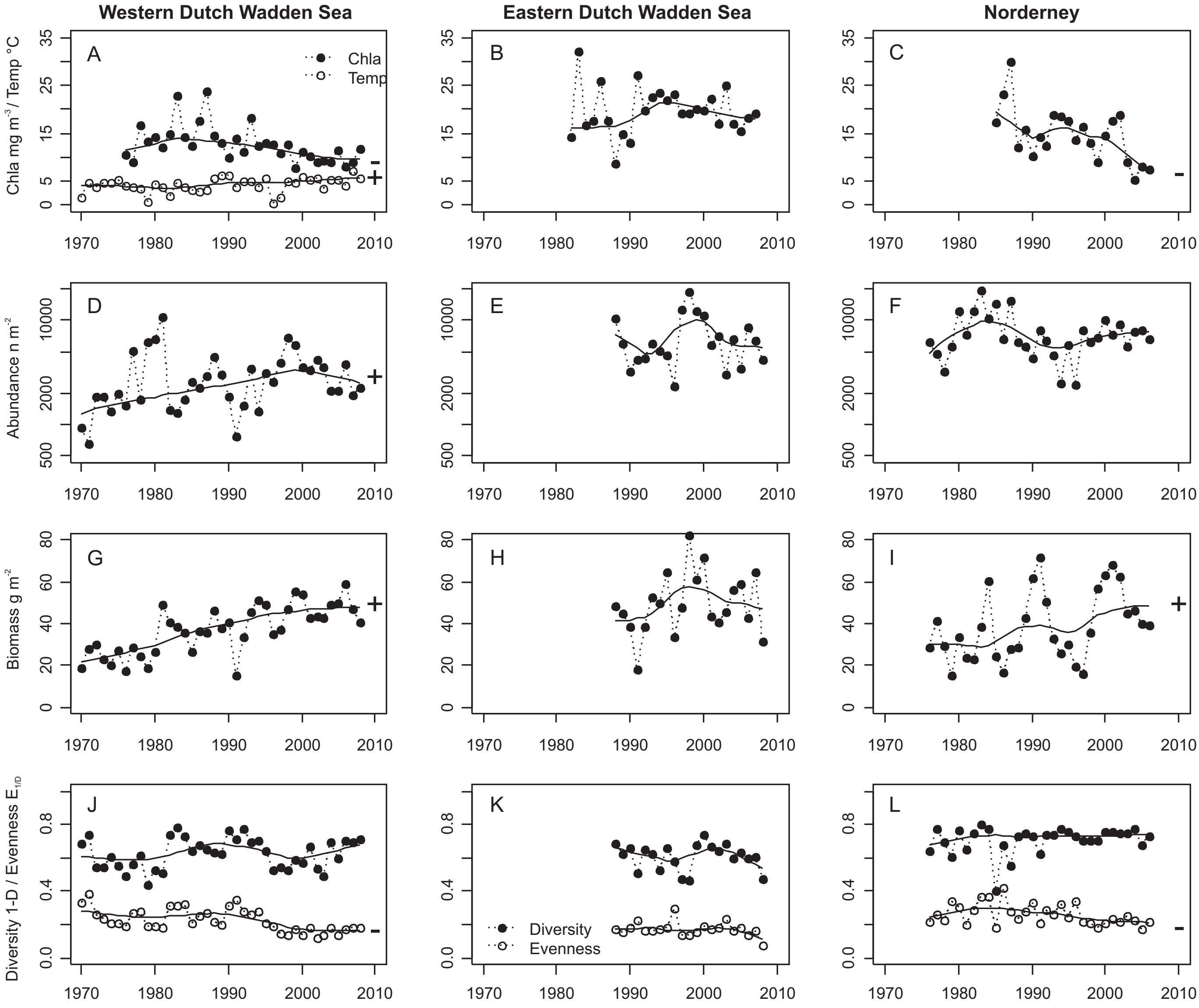

Figure 1:
Time series of environmental variables summer chlorophyll-a concentration (panel A-C) and winter water temperature (A) and abundance (D-F), biomass (G-I), diversity and evenness (J-L) of the macrozoobenthos community in three areas in the southern Wadden Sea. Positive and negative trends are indicated with + and – sign respectively based on Mann Kendall trend tests (Table 1).

Total biomass in late winter/early spring of the macrozoobenthos in the western Dutch Wadden Sea showed a very clear increase between 1970 and 2008 (Fig. 1G, Table 1). During this period it doubled from an average of 24 g m^{-2} in the first five years of the series to an average of 49 g m^{-2} during the last five years of the series. In the eastern Dutch Wadden Sea, there were large fluctuations in biomass around an average of 50 g m-2 with a more than 4 fold difference between minimum and maximum values, but no trend (Fig. 1H, Table 1). At Norderney there was a weak positive trend over the entire time series from 1976 until 2006 (Fig 1I, Table 1). However between 1985 and 2006 when chlorophyll-a data are available there was no significant trend (Table 1). Fluctuations were large, as in the eastern Dutch Wadden Sea.

In all three areas there were no significant trends in the Simpson D diversity time series (Fig. 1J, 1K, 1L, Table 1). In the western Dutch Wadden Sea there was a significant negative trend in the evenness (Fig 1J, Table 1). In the eastern Dutch Wadden Sea and at Norderney there were no trends in evenness (Fig. 1K, 1L, Table 1).

Table 2: Goodness-of-fit of three models relating the rate of change in biomass abundance diversity and evenness of macrozoobenthos to biomass abundance diversity and evenness in the previous year and with covariates chlorophyll-a concentrations of the previous summer, winter temperature and temperature of the previous winter. Degrees of freedom (df), resisual sums of squares (RSS) and Mallow's C_p are given. Lowest Cp indicating the most parsimonious model are printed in bold. Models were fitted for three areas, Western Dutch Wadden Sea (WDWS), Eastern Dutch Wadden Sea (EDWS) and Norderney (NN).

		WDWS			EDWS			NN		
Model	Covariate	df	RSS	Cp	df	RSS	Cp	df	RSS	CP
Abundance										
Constant	-	31	15.05	22.50	18	7.60	54.17	20	6.79	22.80
Linear	-	30	9.52	5.21	17	4.81	30.01	19	3.40	3.91
Ricker	-	30	9.23	4.19	17	6.15	42.63	19	3.78	6.29
Royama	-	29	9.22	6.14	16	2.41	9.62	18	3.38	5.80
Linear	chla	29	9.41	6.81	16	4.64	30.51	18	3.30	5.29
Ricker	chla	29	9.05	5.55	16	5.81	41.42	18	3.78	8.25
Royama	chla	28	9.05	7.55	15	2.33	10.84	17	3.17	6.54
Linear	wT	29	9.51	7.16	16	4.78	31.79	18	3.22	4.85
Ricker	wT	29	9.16	5.93	16	6.11	44.27	18	3.70	7.76
Royama	wT	28	9.16	7.93	15	2.05	8.16	17	3.18	6.60
Linear	wTt-1	29	8.80	4.70	16	2.11	6.75	18	3.02	3.62
Ricker	wTt-1	29	8.32	**3.00**	16	2.65	11.80	18	2.92	**3.00**
Royama	wTt-1	28	8.32	5.00	15	1.60	**4.00**	17	2.92	4.95
Biomass										
Constant	-	31	3.20	21.12	18	2.89	22.77	20	2.35	25.26
Linear	-	30	2.18	6.74	17	1.86	10.67	19	1.97	20.13
Ricker	-	30	2.31	8.88	17	1.91	11.31	19	2.04	21.45
Royama	-	29	2.07	7.12	16	1.86	12.66	18	1.45	12.36
Linear	chla	29	2.17	8.70	16	1.63	9.41	18	1.93	21.36
Ricker	chla	29	2.31	10.88	16	1.58	8.70	18	2.02	23.07
Royama	chla	28	2.05	8.71	15	1.58	10.69	17	1.43	13.85
Linear	wT	29	1.82	**3.00**	16	1.52	7.96	18	1.19	7.37
Ricker	wT	29	1.91	4.44	16	1.60	9.06	18	1.34	10.17
Royama	wT	28	1.80	4.76	15	1.52	9.94	17	0.90	**4.00**
Linear	wTt-1	29	2.15	8.27	16	1.16	**3.00**	18	1.88	20.37
Ricker	wTt-1	29	2.27	10.30	16	1.19	3.35	18	2.02	22.95
Royama	wTt-1	28	2.00	8.01	15	1.16	4.99	17	1.33	12.09
Diversity (1-Simpson's D)										
Constant	-	31	0.71	14.95	18	0.46	21.85	20	0.46	59.41
Linear	-	30	0.52	4.67	17	0.26	7.43	19	0.12	3.14
Ricker	-	30	0.53	5.41	17	0.27	7.89	19	0.13	4.49
Royama	-	29	0.50	5.41	16	0.26	8.96	18	0.12	4.92
Linear	chla	29	0.51	6.64	16	0.26	9.40	18	0.12	5.09
Ricker	chla	29	0.53	7.38	16	0.27	9.86	18	0.13	6.38
Royama	chla	28	0.49	7.33	15	0.26	10.91	17	0.12	6.90
Linear	wT	29	0.46	**3.14**	16	0.21	4.80	18	0.11	**3.00**
Ricker	wT	29	0.47	3.94	16	0.21	5.08	18	0.12	4.76
Royama	wT	28	0.44	4.00	15	0.21	6.63	17	0.10	4.44
Linear	wTt-1	29	0.51	6.57	16	0.19	**3.00**	18	0.12	4.61
Ricker	wTt-1	29	0.53	7.37	16	0.19	3.47	18	0.12	5.76
Royama	wTt-1	28	0.49	6.96	15	0.19	4.84	17	0.11	6.50
Evenness										
Constant	-	31	1.84	6.20	18	1.36	43.82	20	1.93	25.32
Linear	-	30	1.52	**2.00**	17	0.66	14.40	19	0.95	4.81
Ricker	-	30	1.53	2.25	17	0.58	11.08	19	0.98	5.41
Royama	-	29	1.52	3.93	16	0.53	10.56	18	0.95	6.79
Linear	chla	29	1.51	3.73	16	0.66	16.36	18	0.79	**3.00**
Ricker	chla	29	1.52	4.03	16	0.58	12.93	18	0.82	3.78
Royama	chla	28	1.50	5.67	15	0.52	12.44	17	0.78	4.96
Linear	wT	29	1.51	3.76	16	0.48	8.72	18	0.84	4.21
Ricker	wT	29	1.52	4.05	16	0.39	4.62	18	0.84	4.26
Royama	wT	28	1.51	5.68	15	0.33	**4.00**	17	0.83	6.12
Linear	wTt-1	29	1.50	3.49	16	0.44	6.78	18	0.95	6.76
Ricker	wTt-1	29	1.51	3.69	16	0.44	6.72	18	0.98	7.40
Royama	wTt-1	28	1.49	5.45	15	0.44	8.71	17	0.95	8.71

3.2 Temperature and chlorophyll effects

Changes in abundance of macrozoobenthos in late winter/early spring were best described by time series models with the covariate temperature of the previous winter in all three areas (Table 2). In all cases this temperature effect was negative. Including chlorophyll-a in the models did not result in lower C_p values than in the abundance models without a covariate (Table 2). When besides chlorophyll-a, a second covariate, either winter temperature or temperature of the previous winter, was added model results did not improve compared to the models with temperature of the previous winter alone (results not shown).

Biomass changes in the western Dutch Wadden Sea and at Norderney are best described by models including winter temperature. The effect of the previous winter is positive on biomass changes. In the eastern Dutch Wadden Sea, inclusion of the temperature of the previous winter in the time series models generated best results (Table 2). In this case the effect is negative. Only in the eastern Dutch Wadden Sea, the model without covariates improved by adding the covariate chlorophyll-a with a positive (Table 2). Adding chlorophyll-a as an extra covariate to the models including winter temperature or temperature of the previous winter did not improve the models (results not shown).

Diversity changes were most dependent on winter temperature in the western Dutch Wadden Sea and on the temperature of the previous winter in the eastern Dutch Wadden Sea. In neither case did the inclusion of chlorophyll-a improve the simplest model without covariates (Table 2). In the eastern Dutch Wadden Sea, the linear model with covariate temperature of the previous winter improved by adding chlorophyll-a as an extra covariate (RSS of 0.16).

A linear model without covariates describing changes in evenness in the western Dutch Wadden Sea yielded the lowest C_p. In the eastern Dutch Wadden Sea evenness changes are best described by a non linear Royama model with winter temperature as covariate. At Norderney a linear model with covariate chlorophyll-a gave the lowest C_p value. When winter temperature was added as extra covariate to this model, the RSS was reduced to 0.69.

4. Discussion

In two out of three areas chlorophyll-a levels decreased during the period of the time series. This is an indication that the eutrophication status in these areas is declining and is in line with declining nutrient loads in the last three decades (Van Beusekom *et al.*, 2009). However, in one area there were no trends in the chlorophyll-a concentrations, showing that there are regional differences in the development of eutrophication in the southern Wadden Sea. Under conditions of declining chlorophyll-a concentrations, the macrozoobenthos was expected to respond with a declining abundance, biomass and diversity and increasing evenness. The declines in chlorophyll-a were however not accompanied by the expected effects on the macrozoobenthos. In the western Dutch Wadden Sea chlorophyll-a declined but abundance did not show a trend, biomass continued to increase from the beginning of the series while a reversal in this trend is now expected. Diversity did not show a trend, while evenness decreased instead of the expected increase. At Norderney, the decline of chlorophyll-a concentrations was stronger than in the western Dutch Wadden Sea. Abundance, biomass and diversity showed no response, only evenness of the macrozoobenthos showed a trend, a negative one, where a positive trend would have been expected.

Relationships between the exogenous factors chlorophyll-a and winter temperature and the macrozoobenthos metrics described with the time series models showed that the influence of winter temperature on the dynamics of the macrozoobenthos is much more pronounced than the effect of chlorophyll concentrations. In only 3 out of 12 cases the covariate chlorophyll-a concentration improved the models while in only one out of 12 cases temperature did not have an effect.

An important conclusion drawn from this analysis is that the summer chlorophyll-a concentrations do not provide a good predictor of the dynamics of biomass, abundance, diversity and evenness of the macrozoobenthos in the southern Wadden Sea. This is especially remarkable because, even in the western Dutch Wadden Sea, no relationships were found contrary to several earlier studies reporting on the existence of these relationships (Beukema, 1991; Beukema and Cadee, 1997; Beukema *et al.*, 1998; Beukema *et al.*, 2002; Philippart *et al.*, 2007). There are several possible reasons why the present results do not agree with the earlier findings. First, the available time series are longer now than used in the previous studies. In the course of time, patterns may have changed, causing earlier found relationships to become statistically non-significant. Second, chlorophyll-a concentration data used in this paper were from a different source, namely

DONAR, than the NIOZ series used in earlier papers mentioned above. Third, analysis techniques differed between the studies. In this study, focus was on relating between year variability to exogenous factors chlorophyll-a concentrations and also the previously not-included factor, winter temperature, instead of relating to long-term changes. Nevertheless, the absence of a clear and general response of the macrozoobenthos to organic enrichment is in line with conclusions from reviews on this subject by Heip (1995) and Micheli (1999) that phytoplankton and their herbivore consumers are only weakly linked.

In contrary to the absence of an effect of chlorophyll-a concentrations, the general finding of a strong effect of winter temperature on the dynamics of macrozoobenthos agrees well with conclusions of previous work on this subject (Beukema, 1990, 1992; Beukema et al.. 1996; 2000; Essink *et al.,* 1998; Strasser *et al.,* 2003). The paramount effect of winter temperature on macrozoobenthos in the Wadden Sea is thus a very robust finding that is not dependent on the analyzing methods. One of the important effects of winter temperature is on the recruitment success of bivalves. Recruitment success is the main factor determining population dynamics in the main species of bivalves in the Wadden Sea (Van der Meer *et al.,* 2001; Beukema and Dekker 2006, 2007; Dekker and Beukema. 2007). Bivalves are responsible for a large part of the inter-annual variation in the macrozoobenthos (*e.g.* Essink *et al.,* 1998).

In conclusion, the relationship between the dynamics of the macrozoobenthos and the state of eutrophication quantified as summer chlorophyll-a concentrations is at best very weak. Winter temperature, on the other hand, has an overriding effect on the macrozoobenthos in all three subareas considered in this study.

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Vegetation structure of TMAP vegetation types on mainland salt marshes

Martin Maier[1], Julia Schwienheer[1], Klaus-Michael Exo[2], Julia Stahl[1],
[1]Landscape Ecology Group, University of Oldenburg, 26111 Oldenburg,
martin.maier@uni-oldenburg.de (corresponding author), julia.schwienheer@uni-oldenburg.de, julia.stahl@uni-oldenburg.de, [2]Institute of Avian Research „Vogelwarte Helgoland", 26386 Wilhelmshaven,
michael.exo@ifv-vogelwarte.de

1. Introduction

The structure of vegetation has a strong impact on habitat characteristics and ecological processes. Barkman (1979) specifies direct and indirect effects of vegetation structure, for example, influences on germination and establishment of plant species, as well as the creation of microhabitats through differences in temperature, wind, precipitation, light and radiation. Vegetation structure modifies trophic interactions, most obviously on the level of plant-herbivore interactions. Arthropod diversity and abundance (Denno and Roderick, 1991) and grazing preferences of herbivorous geese (van der Graaf *et al.,* 2002; Bos *et al.,* 2005) depend on vegetation structure, but also perceived predation risks and habitat selection of breeding birds (Whittingham and Evans, 2004). Thyen and Exo (2005) and Norris *et al.* (1998) found a significant relationship between agricultural land use and breeding densities of redshank *Tringa totanus* on salt marshes. This was mainly due to the impacts of agricultural land use on the structure and zonation of vegetation. It is suggested that vegetation structure is an important factor for redshank reproduction through provisioning of suitable nesting localities (Thyen and Exo, 2005).

The Trilateral Monitoring and Assessment Program (TMAP), implemented in 1997, is the most important monitoring system in the Wadden-Sea area. The aim is to provide a scientific assessment of the status and development of the Wadden Sea ecosystem, and to assess the status of implementation of the trilateral targets of the Wadden-Sea Plan. One important part of the TMAP is the monitoring of salt marsh areas to provide a comprehensive inventory. To synchronise the vegetation mapping in the three countries involved (The Netherlands, Denmark, Germany), the TMAP vegetation types for salt marshes were defined by an expert panel and first published in the Quality Status Report 2004 (Bakker *et al.,* 2005). Nowadays, virtually all vegetation maps of salt marshes in the TMAP region are based on this typology. However little is known about the structural parameters of the TMAP vegetation types.

The characterisation of the vegetation structure according to the different TMAP vegetation types will provide a tool for extracting information on vegetation structure from available TMAP vegetation maps with the potential of extrapolating data on vegetation structure for most of the international Wadden-Sea region.

The aim of this study is a comparison of different TMAP vegetation types in salt-marsh communities with respect to various parameters of vegetation structure. As previous studies on the vegetation structure of salt marshes identified human land use as a parameter of prime importance (Andresen, 1990; Bakker and de Vries, 1992; Kiehl, 1997), we compared the influence of different types of management (mown, grazed and fallow) on the vegetation structure of the TMAP vegetation types, and assessed the seasonal variation within one growing season.

While the ecological importance of vegetation structure is widely acknowledged in literature, a variable use of definitions and the absence of measuring standards hamper the comparability of studies (*cf.* Zehm, 2006). In our approach, we apply different methods of analysis of vegetation structure to make progress in the search for a standardised method.

2. Methods

2.1 Study area

The study was conducted on mainland salt marshes along the German Wadden Sea coast of Lower Saxony (National Park 'Niedersächsisches Wattenmeer'). All study sites fall within the TMAP area and are mapped regularly within the trilateral monitoring. Data for this study were gathered at three locations: 'Jadebusen' with mown, fallow and grazed salt marshes (N 53° 24'; E 8° 8'), 'Norderland' with grazed and fallow sites (N 53° 40'; E 7° 21') and 'Leybucht' with grazed and fallow sites (N 53° 30'; E 7° 6'). Elevation of the study sites ranged from 1.10 m above sea level (ASL) up to 2.99 m. Grazing intensities are approx. one (head of) cattle per ha. Grazing takes place from end of April till mid October. The mown areas are mown

Table 1: TMAP vegetation types analysed in this study.

TMAP code	TMAP vegetation type
S 1.2	Pioneer zone, *Salicornia* type
S 2.1	Low marsh, *Puccinellia maritima* type
S 2.4	Low marsh, *Atriplex portolacoides* type
S 3.0	High marsh, unspecific
S 3.3	High marsh, *Festuca rubra* type
S 3.5	High marsh, *Artemisia maritima* type
S 3.7	High marsh, *Elymus* ssp. Type
S 3.9	High marsh, *Atriplex* ssp. Type

once a year after the 1st of July and fallow sites have remained without any agricultural land use for at least 20 years. Data were pooled for all sites as there were no significant differences in vegetation structure between the three locations.

2.2 Sampling design

We used random stratified sampling to generate measuring points within each study site (approx. three sample points per ha). Stratification was done according to the latest TMAP vegetation map available. The main measuring period was from the end of June until the beginning of August 2007. To analyse seasonal changes, additional measurements were done for part of the data set between mid April and mid May 2007.

Vegetation data were collected at each plot in a percentage abundance scale. All plot data were classified according to TMAP vegetation types (Bakker *et al.*, 2005; Table 1).

For the definition of vegetations structure we followed Zehm *et al.* (2003) and distinguished vertical (elements in side view) and horizontal structure (*i.e.* light penetration).

Vertical vegetation structure was analysed with a standardized photographic method. At 297 points, we took digital photographs of the vegetation as described in Zehm *et al.* (2003). The software tool SIDELOOK (Nobis, 2005) calculates spatial parameters of the vegetation by analyzing the 'vegetation-pixels' within each photograph. Analysis follows Zehm *et al.* (2003).

Horizontal vegetation structure was measured at 279 points by means of a PAR (400-700 nm) sensor (SunScan, Delta-T Devices Ltd., 1m - array with 64 light sensors). The light incidence at soil level (light penetration through the vegetation) is expressed as a percentage of the light intensity above the canopy. At 178 points we calculated from the 64 light sensors (on a light sensitive surface of 100 cm x 1 cm) the spread of light reaching the soil, as a value for vegetation heterogeneity. All parameters analysed in this study are listed in Table 2.

2.3 Statistical analyses

Data were checked for heteroscedasticity with the Fligner–Killeen test of homogeneity of variances. With no significant differences in variance, we applied one-way ANOVAs and for multiple comparisons Tukey's 'Honest Significant Difference' post-hoc comparison of means with a 95% familywise confidence level. With significant differences in variance present, we used the Kruskal-Wallis rank sum test and for multiple comparisons the Mann-Whitney U test with Holm correction.

For the analyses of the seasonal development of vegetation structure, we calculated the change per sample point over time and divided this value by the number of days between the two measurements ('slope').

All statistical analyses were done using the R statistical software (R Development Core Team 2008).

Table 2: Parameters analysed in this study.

Parameter (codes)	Definition
Incidence of light [%] (incidence.PAR)	Light (PAR) reaching the soil surface, expressed as percentage of the light intensity above the canopy
Spread of light (spread.PAR)	Spread of the 64 light measurements (PAR) at the soil surface with a light sensitive surface of 100 cm x 1 cm
Mean column density [%] (mean.density)	Mean vegetation density calculated from densities per column (10 cm wide stripes of the picture analysed)
Difference of the column densities [%] (diff.density)	Difference of the lowest and highest density per column (10 cm wide stripes of the picture analysed)
Maximum canopy height [cm] (max.height)	Maximum height of the vegetation within each picture
Difference of the column heights [cm] (diff.height)	Difference between the maximum heights per column (10 cm wide stripes of the picture analysed)
Top-line length (tl.length)	Length of the line running along the crest of the highest plant elements divided by the width of the analysed picture
Height reaching specific percentage of density [cm] (pc-50 / pc-75)	Height below which 50% / 75% of the vegetation density is located
Row density [%] (rdX-Y)	Density of vegetation in an area between X and Y cm above the soil surface (10 cm wide rows of the picture)

Table 3: Means, standard deviations and sample sizes of the analysed parameters of vegetation structure. TMAP codes see Table 1, parameter abbreviations and units see Table 2; NA – not available.

		Light measurement				Photographic method / column and global parameters							
		N	incidence.PAR	N	spread.PAR	N	mean.density	diff.density	max.height	diff.height	tl.length	pc-50	pc-75
grazed	S 1.2	5	0.49±0.25	5	0.41±0.20	6	23.53±14.46	6.57±1.80	42.75±21.40	14.9±6.68	5.75±1.58	13.48±5.00	20.03±7.81
	S 2.1	13	0.72±0.14	13	0.19±0.14	37	18.35±8.96	4.96±4.36	30.35±17.75	8.04±6.33	4.62±1.61	9.47±4.53	14.27±7.01
	S 3.0	14	0.57±0.20	13	0.27±0.15	22	19.12±5.05	4.57±3.31	34.16±12.46	12.23±10.54	5.52±1.67	9.68±2.48	14.65±3.77
	S 3.3		NA		NA	7	20.95±8.89	8.64±5.88	39.10±19.00	14.1±7.61	4.67±0.72	10.76±4.44	16.47±7.05
	S 3.5	7	0.31±0.17	7	0.70±0.25	7	36.61±4.67	13.23±6.66	51.64±7.28	11.81±7.48	4.51±0.94	18.36±2.33	28.29±3.39
	S 3.7	7	0.19±0.06	6	0.88±0.14	34	40.14±7.75	9.77±4.51	69.07±14.04	18.4±9.35	3.72±1.36	20.91±4.30	32.34±6.55
	S 3.9		NA		NA	5	40.73±8.23	11.26±6.04	66.56±10.84	18.7±7.85	4.03±1.45	20.72±4.12	32.48±6.23
fallow	S 2.1	78	0.23±0.18	39	0.67±0.27	65	31.77±6.73	11.44±7.64	54.65±18.65	14.15±12.99	4.97±1.56	17.04±3.79	27.04±8.05
	S 2.4	24	0.14±0.09	20	1.11±0.53	21	36.93±6.66	7.63±2.72	52.67±8.29	9.31±4.43	4.25±0.84	18.76±3.14	28.68±4.83
	S 3.3	14	0.15±0.09	6	1.03±0.11	9	38.82±5.96	14.43±5.16	63.12±18.50	19.04±15.53	4.21±0.96	20.1±3.07	31.30±5.92
	S 3.7	53	0.15±0.15	28	0.98±0.36	34	41.52±8.04	11.78±6.44	71.59±17.89	14.15±12.12	5.18±2.63	22.81±7.91	36.32±11.04
	S 3.9	23	0.19±0.21	12	0.86±0.35	17	40.49±9.48	19.71±8.99	73.89±20.72	21.76±13.37	6.14±3.81	22.53±5.07	35.84±8.35
mown	S 2.1	15	0.37±0.15	15	0.43±0.21	15	33.11±7.25	9.03±6.58	47.11±11.48	8.05±5.59	5.41±0.92	16.83±3.71	26.00±6.17
	S 3.7	22	0.20±0.24	14	0.68±0.31	18	53.72±10.70	16.64±8.37	94.85±17.24	15.13±7.77	6.41±2.29	28.76±5.90	45.79±8.85

		Photographic method / row parameters: Row density										
		N	rd0-10	rd10-20	rd20-30	rd30-40	rd40-50	rd50-60	rd60-70	rd70-80	rd80-90	rd90-100
grazed	S 1.2	6	84.02±37.84	74.72±36.05	45.08±45.15	22.3±31.77	6.58±13.52	2 .00±4.90	0.6 0±1.47	0.35±0.86	0±0	0±0
	S 2.1	37	96.06±4.94	53.53±38.80	22.72±33.94	8.23±16.22	2.43±6.35	0.77±2.76	0.19±0.74	0.03±0.16	0±0	0±0
	S 3.0	22	99.05±1.61	70.89±32.89	18.99±16.64	2.27±4.04	0.46±1.34	0.02±0.07	0±0	0±0	0±0	0±0
	S 3.3	7	96.81±3.11	65.1±39.05	34.29±33.29	10.86±15.52	2.10±3.73	0.54±0.94	0.13±0.34	0±0	0±0	0±0
	S 3.5	7	100±0	99.40±0.75	85.63±15.40	60.64±19.91	18.10±13.22	2.46±4.99	0.11±0.30	0±0	0±0	0±0
	S 3.7	34	98.57±4.30	94.80±6.87	84.59±13.66	65.73±22.52	36.99±25.39	13.7±15.27	4.60±7.63	1.90±5.36	0.71±2.08	0.2 0±0.71
	S 3.9	5	99.48±1.16	97.74±3.42	85.54±9.24	69.56±24.65	37.26±28.11	11.56±14.49	4.96±9.01	1.74±3.89	0±0	0±0
fallow	S 2.1	65	96.14±5.63	89.01±12.67	71.77±20.27	39.78±24.05	11.89±12.57	3.44±7.82	1.83±6.55	1.54±5.79	1.22±4.67	1.13±4.71
	S 2.4	21	99.17±3.16	97.29±7.15	88.63±12.26	57.73±25.06	22.00±23.33	4.54±11.19	0.30±0.70	0±0	0±0	0±0
	S 3.3	9	98.67±2.60	95.29±7.23	89.12±7.24	62.88±13.88	27.51±17.75	7.89±14.05	3.44±9.92	1.51±4.53	0.77±2.30	0.78±2.33
	S 3.7	34	96.28±15.55	93.26±14.29	84.83±16.22	63.54±23.34	37.02±23.95	19.15±19.42	10.59±17.66	7.33±18.12	2.87±7.58	0.74±2.27
	S 3.9	17	94.71±8.56	87.11±16.10	80.21±13.79	61.01±19.03	38.65±23.90	21.92±20.14	12.91±14.44	5.74±8.50	2.11±4.18	0.57±1.42
mown	S 2.1	15	99.27±2.34	96.41±4.87	75.16±24.90	42.23±29.79	14.33±17.65	2.94±8.68	0.99±3.82	0.09±0.34	0±0	0±0
	S 3.7	18	96.59±7.46	95.49±7.01	87.22±10.44	78.25±11.29	64.79±18.41	46.38±26.14	30.63±22.89	19.28±18.50	10.61±11.38	5.36±7.82

3. Results

For each analysed TMAP vegetation type (Table 1) the mean and standard deviation of vegetation structure characteristics per agricultural land use scheme were calculated (Table 3).

An analysis of vegetation structure on fallow sites mirrored the natural variation between TMAP types without human disturbance. For the incidence of light and the top-line length we found no significant differences between the TMAP vegetation types on fallow sites (Table 4). However, the most distinct differences occured between the TMAP vegetation types S 2.1 (Low marsh, *Puccinellia maritima* type) and S 3.7 (High marsh, *Elymus* ssp. type), with the latter being significantly higher, denser and more heterogeneous (Table 3 and 4). But also S 2.1 and S 3.9 (High marsh, *Atriplex* ssp. type) differed significantly for

Table 4: Levels of significance for differences between the TMAP vegetation types on fallow sites. Given are the p-values according to Tukey's HSD or Mann-Whitney U test (U). *** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; n.s. not significant. For TMAP codes see Table 1.

	Incidence of light (U)	Spread of light (U)	Mean column density	Difference of the column densities (U)	Maximum canopy height	Difference of the column heights (U)	Top-line length	Height reaching 50 % of density	Height reaching 75 % of density (U)
S 2.4 - S 2.1	n.s.	**	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S 3.3 - S 2.1	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S 3.7 - S 2.1	n.s.	**	***	n.s.	***	n.s.	n.s.	***	***
S 3.9 - S 2.1	n.s.	n.s.	***	**	**	n.s.	n.s.	**	**
S 3.3 - S 2.4	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.
S 3.7 - S 2.4	n.s.	n.s.	n.s.	*	**	n.s.	n.s.	*	*
S 3.9 - S 2.4	n.s.	n.s.	n.s.	***	**	**	n.s.	n.s.	n.s.
S 3.7 - S 3.3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S 3.9 - S 3.3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S 3.9 - S 3.7	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.

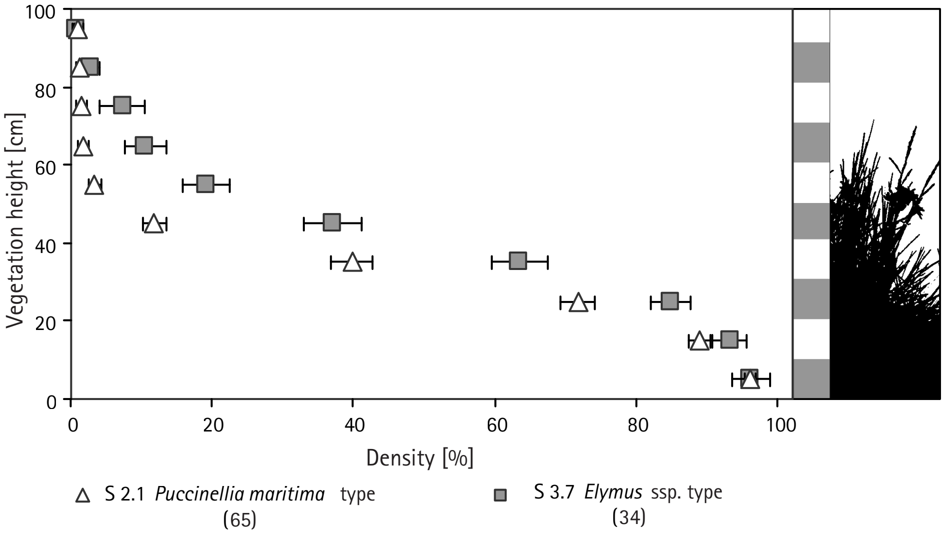

Figure 1: Row density of different heights above the soil surface for S 2.1 (Low marsh, *Puccinellia maritima* type) and S 3.7 (High marsh, *Elymus* ssp. type) on fallow sites.

Table 5: Influence of agricultural land use on vegetation structure of different TMAP vegetation types. Shown are the levels of significance of ANOVA or Kruskal-Wallis rank sum test (K) calculated for each TMAP vegetation type with more than one agricultural land use schemes (Table 3). *** p ≤ 0.001; ** p ≤ 0.01; * p ≤ 0.05; n.s. not significant; NA - not available. For TMAP codes see Table 1.

	Incidence of light	Spread of light	Mean column density	Difference of the column densities	Maximum canopy height	Difference of the column heights	Top-line length	Height reaching 50 % of density	Height reaching 75 % of density
S 2.1	***	***	***	*** (K)	***	**	n.s.	***	***
S 3.3	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.	***	**
S 3.7	n.s.	*	***	**	***	n.s.	***	***	***
S 3.9	NA	NA	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

five different parameters of vegetation structure (Table 4).

At all canopy heights, the *Elymus* ssp. type (S 3.7) was significantly denser than the *Puccinellia maritima* type (S 2.1) except for the lowest 10 cm. Above 70 cm, vegetation density approached values of zero for both types (Figure 1 and Table 3).

Additional analyses focused on the influence of agricultural land-use schemes on vegetation structure. Grazing and mowing as management tools on salt marshes had a strong impact on the structure of TMAP vegetation types investigated: on grazed sites the canopy height was lower and the vegetation was less dense than on fallow sites (Table 3).

When comparing structural components of the two focal TMAP vegetation types *Puccinellia maritima* type and *Elymus* ssp. type (S 2.1 and S 3.7, respectively), we again found less dense vegetation on mown as compared to fallow sites (Figure 2), but for the *Elymus* ssp. type the canopy was significantly higher on mown than on fallow sites ($p < 0.001$; Table 3).

Agricultural land use had a strong and significant impact on most of the structural parameters investigated for the TMAP vegetation types S 2.1 (Low marsh, *Puccinellia maritima* type), S 3.3 (High marsh, *Festuca rubra* type) and S 3.7 (High marsh, *Elymus* ssp. type), whereas there was no significant impact on TMAP vegetation type S 3.9 (High marsh, *Atriplex* ssp. type; Table 5).

As can be expected, we found a very consistent seasonal decline of light at soil level for all land-use schemes. This is attributable to the closing of canopies as the growing season progresses (Figure 3). However, this decline was significantly steeper on mown than on grazed or fallow sites for both focal TMAP vegetation types S 2.1 (*Puccinellia maritima* type) and S 3.7 (*Elymus* ssp. type).

Spatial grazing patterns and forage avoidance by cattle create strong differences in light availability between a *Puccinellia maritima* type (open and short canopy) and an *Elymus* ssp. type (large amounts of standing dead vegetation early in season; Figure 3 left panels top and bottom).

4. Discussion

Vegetation structure is an important determinant of habitat quality, influencing various ecological processes such as seed germination, predator

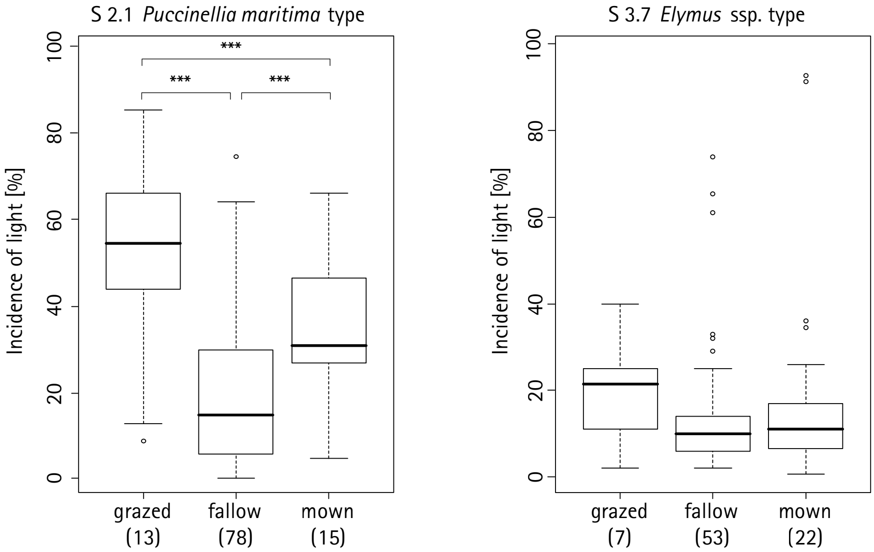

Figure 2: Influence of agricultural land use on the incidence of light. Shown are the TMAP vegetation types S 2.1 and S 3.7 (ANOVA S 2.1 $p < 0.001$ ***; S 3.7 $p = 0.49$).

escape and foraging efficiency. Our knowledge of the mechanisms behind these processes is still fragmentary, especially with regard to the influence of plant structure on higher trophic levels, *i.e.* herbivores and predators. Our study aims at providing necessary background information on vegetation structure of salt-marsh plant communities in order to facilitate further research on plant-herbivore and predator-prey interactions.

This study characterises vegetation structure for the most common TMAP vegetation types on mainland salt marshes (Table 1). Supported by the statistically significant differences found between focal TMAP vegetation types in different land-use schemes, it will be possible to extrapolate our findings to TMAP areas where vegetation mapping provides information on the occurrence of TMAP vegetation types and land-use, and to deduce information on vegetation structure for these areas.

As previous studies (Andresen, 1990; Bakker and de Vries, 1992; Kiehl, 1997) have already

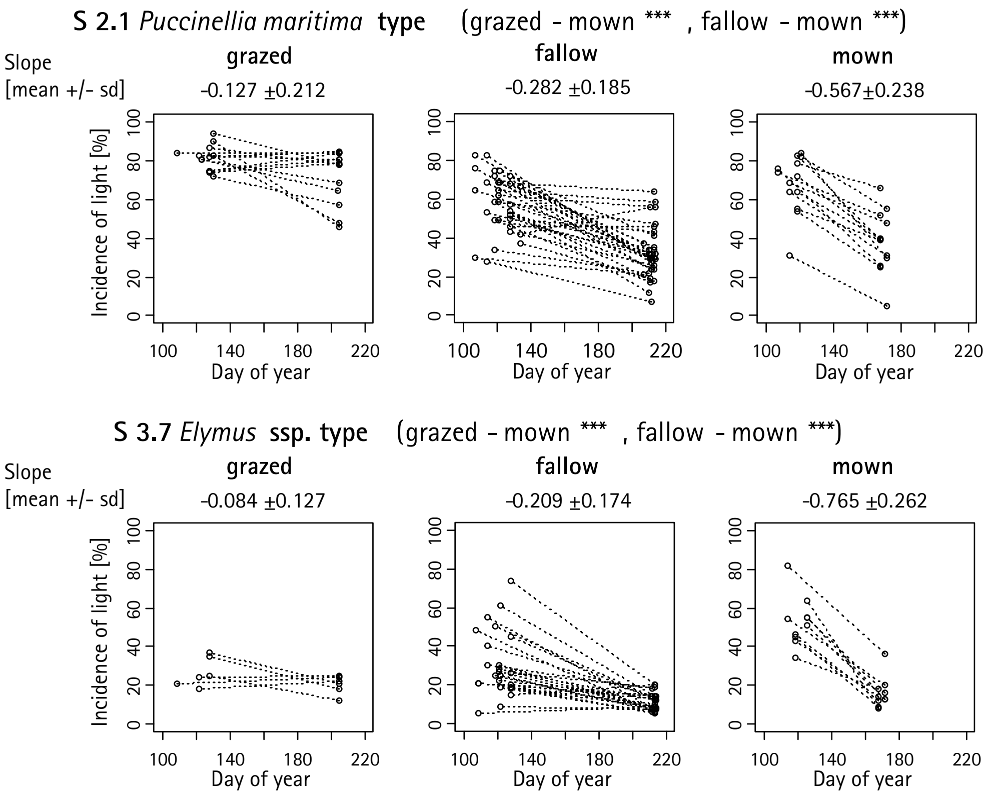

Figure 3: Seasonal development of incidence of light in different land use schemes for two focal TMAP vegetation types. *** $p \leq 0.001$.

suggested, our data confirm the strong impact of grazing and mowing on structural vegetation parameters, specifically canopy height and sward density. For an even more complete description of the structure of TMAP salt marsh vegetation, we suggest that future studies focus on a comparison of mainland and island salt marshes, as well as on inter-annual variation, with repeated measurements in different years.

Seasonal change of the vegetation structure attributable to plant growth is an important component and needs to be taken into account; especially when results are to be transferred to other regions. Therefore, it is necessary to conduct repeated measurements throughout the growing season at the same plots. Our study provides repeated measurements for only a few sample points, but already these first results demonstrate the strong influence of agricultural land use on the development of vegetation structure during the period of plant growth.

In this study, we used two largely differing methods for the analyses of the vegetation structure. On the one hand, a quick assessment of the overall horizontal density of vegetation through light measurements, and on the other hand, the very detailed method of picture analyses in order to assess vertical structure. Both methods are suitable to obtain information about vegetation structure, but provide different parameters. As is often the case in ecological studies, the method of choice depends on the questions asked: for studies on the germination of seeds, the incidence of light is a suitable parameter (Bakker and de Vries, 1992), while for the occurrence of arthropods a more detailed analysis on the density of vegetation in different canopy heights (*cf.* Figure 1) will be necessary.

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Safety and nature go hand in hand

Anky Woudstra, Waddenvereniging, Woudstra@waddenvereniging.nl

Abstract

Nature can help us to adapt to the effects of climate change in the Wadden Sea Area. Natural climate buffers are spatial adaptation to climate change. They revitalise natural processes. They benefit safety and nature. They provide room for other users. And they grow as the climate changes. If we combine climate adaptation measures with restoration measures there will be better public support for restoration of natural processes. And nature can benefit. Natural climate buffers can be created in the North Sea coastal zone, dune areas, mudflats and salt marshes and in the transition zones to the mainland.

1. Nature restoration is necessary but gets little support

Habitat management and restoration is a necessary policy in the Wadden Sea Region. But it is difficult to attain results.

Just to underline this I cite the recent study-report "North Sea and Wadden Sea: nature and policy" from the 'Planbureau voor de Leefomgeving' in The Netherlands: "The current quality of habitats in (the North Sea and) the Wadden Sea is approximately half that of habitats in a pristine state. (...) Regarding the developments between 1990 and 2006, it can be concluded that the quality of the habitats in the Wadden Sea has improved slightly. However it is expected that the majority of policy targets will not be achieved. Solutions can be found primarily in making fisheries more ecological sustainable, in improving water quality and in restoring the natural dynamics." In my presentation I will focus on this last issue: restoration of natural dynamics.

In general there is little support in the area for more natural dynamics. It brings uncertainties, salt water influence, sandy dust and erosion. In The Netherlands we have still not succeeded in restoring estuarine transition zones. Even the recent answer of our minister of Nature Protection to the advice from the Wadden Sea Advisory Council to start pilots of estuarine restoration, is very reserved. Lack of support from farmers is the reason.

Restoration of natural dynamics in the dune area is another issue that provokes a lot of dispute on the islands, as you might have understood from other presentations.

2. Climate change gives opportunities for restoration

Climate change challenges our societies to give serious consideration to the management of the coastal areas. Maybe this gives us an opportunity to restore the quality of natural habitats in combination with adaptation to climate change and sea level rise.

2.1 What is happening as a result of climate change?

The land is sinking

The Netherlands thought it had won the battle against water: the Delta Works were completed, the Zuiderzee became the IJsselmeer and the largest rivers were tamed with dikes and dams. Water is imprisoned in asphalt, steel, basalt and concrete, but the cost of maintenance is rising by the day. At the same time, The Netherlands is sinking, due to intensive draining and natural processes such as silting and peat formation that have been halted. Several regions in the Northern coastal area are sinking due to gas and salt extraction.

The sea is rising

According to IPCC climate experts, the sea level has never risen as rapidly in such a short time as it is doing now. As a result, it is becoming increasingly difficult in The Netherlands to let rivers, storage basins and the IJsselmeer drain freely into the sea. This is particularly true during the combination of north-westerly gales and heavy precipitation, which is occurring more and more frequently.

Coastal area flood protection will require major investments. Even the survival of the Wadden Sea is not self-evident. Another danger is emerging during dry periods. When river levels are low, increasing amounts of salt will find their way into the rivers because of the rising sea level. The shallow groundwater also becomes brackish. This is already a major problem for a number of water companies and arable farming, and also on the islands.

It becomes wetter and drier

Extreme precipitation is causing more and more flooding in river and stream basins, with damage to built-up areas, farming, etc. In cities, severe rainfall results in flooded basements, tunnels and overflowing sewer systems.

On the other hand, increasingly smaller glaciers in the Alps and longer dry spells in the summer are causing more droughts. A decrease in water drainage of 60% is conceivable! In this scenario, the Waal river could almost be crossed on foot.

The heat is on

Cities are urban heat islands: buildings absorb heat and break the cooling wind. During a heatwave, for example, the centre of London can be 9°C warmer than the surrounding area. In combination with higher air pollution during hot periods, this results in additional incidences of death. Higher temperatures in water bodies increase the possibility of botulism and blue-green algae. The distribution area of terrestrial animal and plant species will move northward; marine species also behave in this way. However, not all species succeed in keeping pace with the changes.

2.2 Adaptation is necessary; natural climate buffers can contribute

As a society we must be prepared for the impacts of climate change on our economy, our health, our ecosystems, and our safety. We must find ways to deal with increased flooding, more severe droughts and hotter cities.

A coalition of seven Dutch nature NGOs, including the Wadden Sea Society, explored how natural processes can contribute to 'climate-proofing' The Netherlands. We developed the concept of 'natural climate buffers'. They can make a major contribution to climate-proofing The Netherlands, as they are able to adapt to and keep up with climate change.

A natural climate buffer is a spatial adaptation to climate change; it revitalises natural processes; it is beneficial for human safety and for nature; it creates room for other users; and it grows as the climate changes.

Climate buffers are beautiful

Climate buffers are beautiful, water rich areas that offer great opportunities for outdoor recreation and waterfront housing. And they offer numerous other benefits. For example, water retention in climate buffers will help our economy (securing water supplies for cities, farmers and industries), moderate our local climates (reducing urban temperatures during hot summers), improve our safety (halting peat land subsidence), and preserve our ecosystems (providing habitat and maintaining biodiversity).

Climate buffers are an economically attractive alternative

Climate buffers will cost millions of euros. But considering that they will help to prevent billions of euros of flooding damage and positively affect the quality of life and health of people in surrounding towns and cities, it is clear that the costs of climate buffers will be fully compensated by their benefits. Moreover, calculations have shown that climate buffers often prove more economically attractive than present land and water management strategies. The societal significance and multifunctional character of natural climate buffers ensures public support and allows financial resources to be pooled.

3. Adaptation by natural climate buffers in the Wadden Sea area

In terms of coastal protection, the Wadden Sea area is essential for the safety of the Northern region. Tidal mud flats and salt-marshes minimize the impact of sea waves on the dikes.

The earth is growing warmer however and the Wadden Sea will not be spared the consequences.

Due to sea level rise, the mud flats will be permanently submerged, dikes and dunes will suffer more from gales, and waves will hit the coast harder. Rising sea temperatures will increase the risk of algal blooms and low oxygen levels and species from more southerly latitudes will migrate into the area. Rivers will have to cope with extreme precipitation, leading to peak discharges.

The Second Dutch Delta Commission (under the chairmanship of ex-minister Cees Veerman) concluded last summer that the continued existence of the Wadden Sea is not self-evident.

We conclude that because of climate change, the coastal protection, natural qualities and economic benefits of the Wadden Sea area are at stake.

Existing techniques to resist the consequences are expensive and detrimental to the character and resilience of the landscape. Restoration of the Wadden Sea area as a natural climate buffer is another way to accommodate the effects of climate change.

3.1 Super natural climate buffer

As we all know, the Wadden Sea area is shaped by the wind, tides and waves. They carry sand and silt which settles in the Wadden Sea and the isles and nutrients which are essential for the area's rich flora and fauna. The processes that form the landscape are indispensable to the Wadden Sea. The Wadden Sea Area is, so to speak, a 'super natural climate buffer'.

But although these centuries-old processes continue to this day, due to man's influence they are no longer as pronounced as they once were. In order to be able to live in this area, mankind has constrained many of the natural processes. There are only a few dynamic transitional habitats left between the sea, beaches, dunes, salt marshes, mud flats and rivers. There is too little space for the development of new dunes and salt marshes, and biodiversity is declining on the mud flats.

3.2 Co-creation

Because natural climate buffers serve coastal defence in the first place, with benefits to nature a secondary consideration, the authorities, interest groups and people in the Wadden Sea area incline to support the realisation. But if climate buffer restoration projects are developed only by experts (from the mainland) and nature conservation organisations, people feel inclined to resist.

That is why we suggest another route. In April, we start organising special workshops (in Dutch: 'schetsschuit') in several regions. And we invite all relevant actors to co-create a spatial adaptation to climate change. The only criteria we use are:

- revitalisation of natural processes;
- benefits for human safety and for nature;
- multifunctional use; and
- adaptability to cope with changes in the climate.

During these workshops there is emphasis on information exchange, increasing people's knowledge of the actual situation (through a fieldtrip and expert contributions), representation of all relevant interests and 'out-of-the-box' thinking.

We expect participants to become supporters of natural climate buffers; in the longer run they will behave as ambassadors. We also expect that these workshops will influence policy documents such as the National Waterplan and the Delta Programme. Even the Trilateral Management Plan can benefit.

4 How to become a success

4.1 Sand supplementation as natural climate buffer

To preserve the functional significance of the Wadden Sea area, the supply of sand and sediments to the area must be increased, and erosion and sedimentation processes must be given free rein. It is our opinion that this is the only way that the Wadden Sea, the dunes and tidal marshes can keep pace with the rising sea level and keep waves from impacting the coast.

Sand supplementation along the Dutch coast for safety reasons has been under way since the beginning of the 1990s. The Wadden Sea population, including the Nature NGOs, support this method of coastal defence. On the other hand, we don't know very much about the relation between supplementation and sand import into the Wadden Sea. There is also a lack of knowledge about the effects on the ecosystem of the North Sea coastal zone, the Wadden Sea (like turbidity) or the (dynamics of the) dune area of the islands.

Better monitoring can give us a lot of information about the effects of sand supplementation. In 2010 almost 10 million cubic metres of sand will be supplemented on Ameland. This delivers us a perfect opportunity to improve the monitoring plan.

The recently made agreement with the Minister of State of Transport and Public Works to seek to establish optimal levels of sand supplementation along the Dutch coast, especially the Wadden Sea coast, can be very valuable in this respect. Our interest for a research programme centres primarily on:

- the quality of sediment imported into the Wadden Sea and the turbidity that results;
- the relationship with dynamic dune management, including wash-overs;
- the effects of large scale supplementation along the coast of Holland;
- and the possibilities of supplementation in the outer deltas or the Wadden Sea itself.

And when it comes to combining sand supplementation with dynamic coastal management there is a lack of local support. That is why we propose to develop several experiments via a 'schetsschuit'. These experiments have to deliver knowledge by research and monitoring and can help establish the necessary support from society. And the results should be carried over into policy.

This all is very much in line with last week's advice from the Dutch Advisory Council for the Wadden Sea to start now with large scale monitoring and research on sediment transport and sand supplementation. And on a policy level, the Delta Programme that the Dutch Government is developing seems to be relevant.

4.2 Dunes as natural climate buffers

To attain the objectives of the Habitats and Birds Directive for the dune area and salt marshes on the islands, dynamic dune management is very much wished for. Some experiments have been carried out and the theoretical approach has been developed in The Netherlands by the restoration working group for the islands. (see 'Natural islands', to be published in English within a few months.) Other speakers have given more information about this subject.

4.3 Mud flats and salt-marshes as natural climate buffers

To follow sea level rise and to cope with other climate change pressures, a healthy ecosystem in the Wadden Sea is the only solution. We realise more and more that mussel and oyster banks, seagrass fields and salt marshes are indispensable as ecosystem builders. To know more about sediment trapping and sediment's role as a breakwater, we recommend monitoring the effectiveness of varying quantities of supplementary materials during restoration projects.

The shellfish agreement in The Netherlands gives opportunities to experiments in the coming years. Monitoring and research should deliver more knowledge about their climate buffering role. Even though there is not much opposition to these experiments, they should be developed together with relevant actors. Discussion between experts does not in itself win widespread policy support and local authorities can become ambassadors in this way.

4.4 Dikes as natural climate buffers.

We also recommend that the transition between land and water should be made more gradual, to cushion the impact of waves and reduce flooding risks for the Northern coast. The feasibility of double seawalls, dikes resistant to overflow, estuarine transitions and 'wash-overs' should be considered.

These are all perfect subjects for a 'schetsschuit'. And there is still need for a great deal of knowledge: which role do salt-marshes play in coastal defence? Is it feasible to adapt agricultural practises to brackish circumstances? Are the hydrodynamics of the Wadden Sea changing and how does this influence the dikes?

5. Conclusions

- Climate change gives us an opportunity to restore natural habitats in combination with adaptation to climate change and sea level rise.
- Restoration and revitalisation of natural processes by 'natural climate buffers' can help the Wadden Sea area to survive, for the benefit of people and nature.
- The development of habitat restoration measures should be combined with the development of adaptation (to climate change) measures in order to win local support for the revitalisation of natural processes.
- Spatial adaptation in the Wadden Sea area can best be developed by co-creation.
- Creation of natural climate buffers should follow the criteria: revitalisation of natural processes; benefits for human safety and nature; multifunctional use; and adaptable to the extent of climate change.
- Sand supplementation is the most crucial adaptation measure; a large scale research and monitoring programme should be developed.
- Dynamic dune management is only feasible if supported by communication and information.
- We need to do experiments to deliver knowledge about the role of salt-marshes and other ecosystem builders in trapping sediment.
- The feasibility of gradual transition zones can only be considered by co-creation with local actors and with the input of knowledge.

High tidal flats, salt marshes and managed realignments as habitats for fish

S. Colclough*, L.Fonseca, W.Watts and M.Dixon, Environment Agency, Rivers House, Belvedere Road, Abbey Wood, London, UK.

Abstract

This paper examines the fish related elements of a recent Interreg IIIb project, Comcoast. The work follows naturally from a study reported by the same authors in 2005. With British, Dutch, Danish, German and Belgian partners, Comcoast sought to define best practice in the field of innovative flood risk management design to meet the twin challenges of sea level rise and more frequent storm surges associated with climate change. The UK element of the project attempted to describe all of the multifunctional benefits that managed realignment treatments might provide. The paper provides information on the seasonal usage of the sites by fish, on their feeding behaviour and early work on semi-quantitative studies of fish usage of the habitats. Early guidance on site design issues, to maximise fish and fisheries benefits of such treatments, is provided and reference is made to emerging policy, ecosystem evaluation and future research. Some observations from related fish studies in extant mature salt marshes elsewhere in the UK are also included. Further papers from the Comcoast project on fish and fisheries, geochemistry and socio-economics will appear in due course.

1. Introduction

Intertidal habitats, particularly salt marshes, are a valuable, but diminishing resource. They provide critical chemical and ecological functions, and contribute to flood defence by dissipating wave energy (Dixon, Leggett and Weight, 1998). These habitats are now being compromised by the cumulative impacts of a range of anthropogenic pressures including agriculture, port development, harbours, barrages, industry, recreation and housing. Attrill, Bilton, Rowden, Rundle and Thomas (1999) reported that land claim has affected 85% of British estuaries. In some instances, over 80% of the intertidal area has been lost. Habitat loss through encroachment is an extreme pressure in estuaries. In the Thames estuary in the UK, less than 1% of the original bank form still remains (Colclough *et al.,* 2002). Coastal squeeze due to sea level rise (Crooks and Turner, 1999) is adding to this pressure. The South-East of England is particularly vulnerable because of post-glacial land subsidence caused by isostatic rebound. 2% of English salt marshes are lost every year as a consequence of sea level rise (Dixon *et al.,* 1998). Salt marsh habitats support distinctive plant communities and associated fauna: they are important feeding, breeding and roosting grounds for birds (Rupp and Nicholls, 2002). Salt marshes and other intertidal habitats are UK Biodiversity Action Plan habitats.

Since 2000, climate change and sea level rise have been recognised in the UK as requiring a new approach to flood risk management. One element is the creation of new intertidal habitats by realignment of the historic defences to provide more flood storage, and in particular cases, to provide energy attenuation during storm surge events (Dixon *et al.,* 2008). Prior to this date, there was little awareness in most of Western Europe of the importance of high intertidal habitats for fish life. There is a substantial body of North American work demonstrating that intertidal habitats such a salt marshes are extremely important as refuge, feeding and nursery areas (Roundtree and Able, 1992; Peterson and Turner, 1994; West and Zedler, 2000). This habitat is also under threat, but the impacts of loss have hitherto unrecognised negative socio-economic impacts. Bell (1997) reported that 68,000 ha of coastal wetlands were lost through urban development in 48 US States between 1950 and 1970, with consequential serious loss of production of a range of commercially important fish species.

European workers began to note strong associations of fish species with high intertidal habitats in the 1990s (Laffaille *et al.,* 2000; Lafaille *et al* 2001; Lyndon *et al,* 2002). Laffaille *et al.* (2001) noted positive association of the early life stages of 0-group bass *Dicentrarchus labrax* (L.). with macro-tidal salt marshes in Mont Saint-Michel Bay (France). The authors demonstrated that primary and secondary production of intertidal salt marshes plays a fundamental role in the feeding of these fish. They postulated that the nursery function usually ascribed to subtidal and intertidal flats should be extended to the supratidal, vegetated marshes and to salt marsh creeks. Lyndon *et al.* (2002) noted active movement of fish onto the high intertidal habitats during the flood and then their return to deeper water on the ebb.

The first substantial work in England to study fish use of salt marshes and other high intertidal habitats began in 2003 at the Abbotts Hall managed realignment in the Blackwater Estuary, Essex, some nine months after five breaches were made in the original sea wall. Studies were rapidly expanded to other realignment sites in the same estuary, Orplands (created in 1995) and Tollesbury (1995) and to two sites on the Thames. This work has been fully reported in Colclough *et al.* (2005). A multi-method sampling strategy was applied repeatedly through the summer months. Large numbers of a broad range of fish species were found, with active movement of the fish across the sites, as previously reported by Lyndon *et al.* (2002). Microhabitats provided by fresh vegetation at the Abbotts Hall realignment site proved to be particularly beneficial to the fry of bass, common goby (*Pomatoschistus microps* (Kroyer), sand goby *P. minutus* (Pallas) and sand smelt (*Atherina presbyter* (Cuvier), all observed in clear water conditions in close association with vegetation stands. Colonisation by salt marsh plants has been faster here than has been observed on earlier sites. This may reflect the use of regulated tidal exchange to prepare the site before the main breaching, and breach timing, chosen when the maximum seed bank is available in the estuary (K. Thomas pers. comm.). Abbotts Hall is also notable for the broader range of habitats available, spread along a significant gradient. Herring *Clupea harengus* (L.) were rarely captured, but 2000 0-group herring were taken from a ponded waterbody which retains 1 m of water at low tide. This pond is a remnant of the former borrow pits created when the original 17th century walls at Abbotts Hall were created (Colclough *et al.*, 2005).

2. The Comcoast project

Comcoast (COMbined function in COASTal defence zones) was a North Sea Interreg IIIB project which ran from April, 2004 until September 2008, funded by the Community Initiative Programme in which The Netherlands (lead partner), the United Kingdom, Germany, Belgium and Denmark were participating. The prime aim was to promote and implement an integrated approach to improving coastal defence systems. Subsidiary aims were to identify and understand the social, economic and technical opportunities and constraints of innovative coastal and flood risk management techniques and the delivery of a more sustainable environment. Objectives were set to share knowledge and expertise on improvement of coastal defence infrastructure and sustainable development; on stakeholder participation and on the design, implementation and monitoring of pilot projects. From a UK perspective, Comcoast also complimented the Environment Agency's development of a more strategic approach to flood risk and Shoreline Management Plans. Recommendations would be provided on the economic valuation of innovative techniques involving the constructive use of coastal and estuarine wetlands using the Habitats and Water Framework Directive as the main legislative drivers.

Three UK sites were studied. Abbotts Hall has been fully described in Colclough *et al,* (2005). Horsey Island is a 80 ha old salt marsh where beneficial re-use of marine dredging was employed to raise the marsh level. Wallesea Island is a 115 ha realignment breached in 2006, and created to compensate for the aggregate loss of 54 ha of mudflat and salt marsh habitat in the Medway and Orwell estuaries. Three interlinked PhD programmes were established to study: fish utilisation of the newly created habitats and adjacent mature salt marshes in more detail; the geo-chemistry

Figure 1: The main managed realignment sites in the UK

Figure 2: Abbotts Hall realignment six months before the main breach in October 2002 (regulated tidal exchange in operation).

of these sites; and to provide an economic overview. By interlinking these studies, an overall objective was to identify and describe as many functions of the intertidal habitats as possible. This would then permit guidance to be developed on site creation with complimentary suites of functions and after-uses. At the outset, these functions were perceived to include flood risk management, biodiversity, fish nursery provision, carbon sequestration and nutrient cycling. Outputs from the three PhD studies are still awaited. Some interim results from the fish studies will be briefly reported here.

3. UK fish studies in the Comcoast project

Colclough *et al.* (2005) provided an overview of fish utilisation in the intertidal habitats studied. More focus was determined for Comcoast to study, in particular, the seasonal use of the habitats by juvenile fish, feeding habits of 0-group bass, semi-quantitative fish sampling and the possibility of shellfish culture. As well as the three Comcoast sites listed above, additional fish sampling also took place at Orplands and Tollesbury.

3.1 Seasonal use

For this purpose a larger version of the fixed trap described in Colclough *et al.* (2005) was staked out at low water at fixed locations. The net is essentially a large funnel structure (2 m in total length) with a 1m x 1m entrance. The mesh is 4 mm knotless mesh. A large cod end is composed of 1 mm knotless mesh. The net was recovered at mid-tide before access was compromised. Nets were deployed at monthly intervals over a 24 month period. Most of the fish utilisation of the intertidal habitats studied took place between May and October. Some species demonstrated more focussed use. For example sprat *Sprattus sprattus* (L.) used the sites early in the spring, whereas thick lipped grey mullet *Chelon labrosus* (L.) used the site in the late autumn. Certain species such as bass and common goby demonstrated different patterns of utilisation at different ages.

3.2 Bass feeding ecology

The same nets provided significant information on the feeding ecology of 0-group bass. At Abbotts Hall, Orplands and Tollesbury, the nets were deployed on particular flood and ebb tides to assess the overall gut fullness of 0-group bass. Studies of 0-group bass using salt marshes in Mont Saint Michel Bay had shown that the extent of gut fullness was always greater in fish captured on the ebbing tide than on the flood (Laffaille *et al.*, 2001). The authors considered this as evidence of the active use of the high intertidal habitats by the bass and a measure of the benefit derived from this activity. Using methods modified after Laffaille, a similar result was obtained at all three sites. In a second study, a clear shift in dietary preference was demonstrated for 0-group bass as they grow. The dietary elements most commonly found in the guts of the youngest bass were most often found in the high areas of marsh, tending to support observations by Laffaille *et al* (2000), that smaller size classes of bass fry move further into the higher marsh.

Detailed studies on fish utilisation and the feeding ecology of 0 group bass will appear in future publications arising from the Comcoast PhD programmes.

3.3 Semi-quantitative fish sampling

Given the highly dynamic nature of intertidal habitats, conventional wisdom would suggest that quantitative sampling of highly mobile fish populations is not practicable. However, using methods and rationale employed in Mont Saint Michel Bay (Laffaille, *et al.*, 2000) some semi-quantitative sampling was conducted late in the Comcoast project. A much larger version of the rectangular static nets described in Colclough *et al.* (2005) was developed for this purpose. The

Figure 3:
Semi-quantitative sampling at Tollesbury.

total length of the net was 3 m with a 1.5 m gape. The main body of the net was constructed of 4 mm knotless mess with a 1 m cod end in 1 mm knotless mesh. Twin 5 m x 1 m wings were attached to the net.

For successful deployment of this net, a detailed knowledge of tidal behaviour across the site at all tidal states had to be developed first. Mature salt marshes adjacent to the Tollesbury realignment proved to be the best location for this approach. Sites and tides were then selected where the flows would enter and leave discreet areas of marsh via the same channel. The net was then deployed at low tide in the channel, staked out and laid flat on the channel bed. At high water the net was raised rapidly. If chosen correctly, all of the fish which had used a measurable surface area of marsh upstream of the net would be captured on the ebbing tide. In practice, difficulty was experienced in ensuring that the surface areas were fully discreet at high tide. Actual tidal heights can vary from predictions in these waters due to offshore wind conditions (Dixon, M., pers. comm.) In such situations small block nets had to be deployed to try to maintain integrity.

The fish species captured in these fixed nets were as described above and in Colclough *et al.* (2005). Great variation in the numbers of fish taken was noted over the six occasions on which this net was deployed. Long-term datasets will need to be established on fixed sites before this methodology can describe typical abundance ranges with any degree of confidence. However, the drive towards ecosystem evaluation of these habitats, described later, will dictate that this area of work is taken forward.

3.4 Shellfish Culture

There is significant shellfish capture and culture in the Blackwater Estuary. Trial cages of the cockle *Cerastoderma edule* (L.) were established in the permanent pond feature at Abbotts Hall and in one of the new permanent ponds created at Wallasea Island late in the Comcoast project. Survival and growth was good in all cages for the short period of the study. Since the project ended, oyster fishermen in the Blackwater Estuary have agreed to deploy trial cages of the native oyster *Ostrea edulis* (l.) in areas of the Abbotts Hall site. To date these trials have been very promising.

4. Other UK sites studied

Opportunities have been taken since 2005 to extend the methodologies developed through Comcoast and the work leading up to it, to other areas of intertidal habitat. Often this has been conducted in collaborations in support of local biodiversity challenges or as educational initiatives to demonstrate value for fish life. These include studies conducted in the Adur estuary at Shoreham, Sussex, the Deben estuary in Suffolk, Fforyd Bay and Malltreath in North Wales, a managed realignment on the Humber at Alkborough, the Boyne and Liffey estuaries in Eire and an extensive area of intertidal freshwater woodland in the Scheldte estuary near Antwerp in Belgium. In all of these sites, juvenile fish have been an important component of the wildlife associated with the habitats available (Colclough S., unpublished*)*. The last habitat described is very rare in the UK (Vandenburgh E., pers. comm). Graff and Middleton (2001) describe this habitat as providing refuge areas for a range of important conservation species in the United States.

5. Lessons learnt about habitat design

Design philosophies for managed realignments are evolving rapidly. The herring captured in the permanent pond at Abbotts Hall led directly to the inclusion of a number of large permanent deep water features (>1 m) at Wallesea Island. These ponds were then found to be important to range of fish species in the latter part of the Comcoast project.

Conclusions drawn to date from experiences gained on UK managed realignments have recently been summarised by Dixon *et al.,* (2008). This summary is now being used to offer design guidance for new treatments, in lieu of the final outputs from the Comcoast project. Some of the main conclusions are described here in brief. Realignment options should be chosen which require a minimum of engineering other than the breaches. A new gradient will tend to encourage salt marsh development in front of the new wall, offering erosion protection and also tends to encourage a rich diversity of habitat types. Gradients may be created by bunding dredged material to the rear of the site. Creating creeks and channels can help mudflat development by increasing drainage and habitat complexity, but deeply incised channels tend to be unstable, support less vegetation and provide less favourable fish habitat. A diverse habitat structure will support intertidal mudflats for feeding birds, tidal lagoons, creeks and ponds for fish feeding and nursery areas and upper zone marshes for roosting and nesting birds, reptiles and mammals.

Figure 4: Seine netting on Sutton Marsh, Deben Estuary, Suffolk, July 2007.

6. Future Work

A number of strands of further work are underway or envisaged. More long-term information is needed on the seasonal use of sites by fish, the association of fish with habitat structure and more robust quantification of the usage made. More geo-chemistry work is required to fully elucidate all of the functions of these habitats. New work is planned on the air quality benefits that may be associated with intertidal habitats.

A new 600 ha site at Wallesea Island, immediately adjacent to the existing site is planned. Design criteria developed through Comcoast will be incorporated into this new site and hopefully elsewhere in the UK as opportunities arise.

Fish monitoring should be built into post-project monitoring regimes for managed realignment, given current knowledge on fish utilisation. Post Comcoast, this has now been achieved for the first time on the Alkborough site on the Humber (Wynn P., pers.comm.)

Nearly all of the extant managed realignments in the UK created to date function as protected biodiversity resources with limited public access or riparian interest. Further studies are planned to develop alternative models which will provide demonstrations of other potential after-uses. These may include saltwater or brackish water agriculture, with crops ranging from salt marsh reared sheep to salad crops such as *Salicornia* spp, shellfish culture, recreation and amenity, saltwater angling and moorings/navigation.

7. Policy development associated with intertidal habitats

The fish nursery and other functions now identified tend to add new weight to protection and enhancement of these habitats. The strong association of juvenile fish tends to suggest that all such habitats must be an integral part of the local Good Ecological Status under the Water Framework Directive. Given the historic losses, a powerful new driver emerges to protect all of the remaining habitat and promote the creation of much more. This logic is now being employed in the UK in planning and development control dialogues with developers, alongside Habitats Directive measures.

An ecosystem services approach to evaluation of these habitats is under way, but will be dependant on further description of the functions identified. Early evidence through the Comcoast project and elsewhere in Europe suggests relatively high values are achievable (5,000 Euro $ha^{-1}yr^{-1)}$ (Watts W., pers. comm.). Outputs are increasingly being used in development issues such as the Severn Tidal Power project to drive more sustainable solutions, in tandem with existing Habitats Directive considerations.

As the functions associated with intertidal habitats become more fully described, additional funding streams may be attracted to support habitat creation, over and above the flood risk management requirement. When fish utilisation has been more fully described, it is possible than contributory funding for site creation could be derived from the structural funds of the Common Fisheries Policy. This could be especially important in the context of more sustainable future marine fisheries management given the historic loss of such habitats. Early contact with DG Environment has shown support for this view of contributory funding. McLusky, Bryant and Elliott (1992) estimated that the fish production associated with the Forth estuary would be some 66% greater if the historic land claim over the past 200 years had never occurred. In future, similar arguments about contributory funding may apply to carbon sequestration, nutrient cycling and air quality functions (Watts W., pers.comm).

The newly described value of intertidal habitats for juvenile fish has implications for future broader marine management. Under the UK Marine Bill, Marine Conservation Zones may well now reflect the socio-economic value that intertidal areas provide as vital marine fish nursery grounds in future designations.

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The Danish Houting Project

Jan Steinbring Jensen, Ministry of Environment, Denmark,
Forest and Nature Agency, Wadden Sea Dep.

1. The Houting

The houting *Coregonus oxyrhunchus* is a small salmonoid fish species belonging to the whitefish family. At present it is only found in the Danish part of the Wadden Sea and the rivers that run into it. Formerly it was spread all over the Wadden Sea area from The Netherlands in the south up to Denmark in the north. However pollution, excessive fishing and physical degradation of the rivers made it extinct in The Netherlands and in Germany and its population in Denmark was reduced to an absolute minimum.

The lifecycle of the houting is straightforward. As an adult it stays in the Wadden Sea and in November and December it moves into rivers for breeding. The eggs are spawned freely into the water where they are fertilized. Afterwards, the eggs attach to gravel and perennial water plants. The eggs hatch in January and the small fry drift passively down the river until they meet shallow, stagnant water in the lower parts of the river. Here they primarily feed on zooplankton and at the end of May, at 5-8 cm long, young houting move out into the Wadden Sea and return to freshwater for spawning after two or three winters in the sea. The houting can grow up to 15 years old and may spawn several times during its lifespan.

The houting is regarded as a relatively poor swimmer compared to other salmonoids, and it it is unable to overcome even minor obstacles in the rivers, so weirs and dams therefore constitute a total blockage of houting migration. Thus, the houting may be regarded as an indicator of an authentic, well functioning Wadden Sea ecosystem since it is totally dependent on unhindered access to its spawning grounds, good ecological river quality and needs large areas of water-covered wetlands. These three factors have all suffered severely under the urbanising and development of intensive agriculture in the Wadden Sea area.

2. Project background

In 1980, the fish was totally protected by Danish law and the houting is listed under the annex to the Habitats Directive as a prioritized species, which gives Denmark a special responsibility for this species. There are only two species in Denmark under this category and only concerns about the

Figure 1: The houting *Coregonus oxyrhunchus* (Photo: Hans Ole Hansen)

nation's safety or people's health take higher priority than concerns for the houting. All of the Danish Wadden Sea, including the lower to middle parts of 6 river systems, is designated under the Habitats Directive to protect the houting as part of the Natura 2000 network.

In the 1980s, houting populations in the Danish rivers reached a critical low level and a huge restocking programme was initiated. The young houting are quite easy to rear artificially and during the early 1990s more than one million young houting were restocked and the populations built quite rapidly to more 100,000 adult spawners.

However, when the restocking programme was halted, populations soon dropped to the critical level again and in 2000 the adult spawner population was estimated to be around 7,000 fish.

3. The project

Recognizing its responsibility, the Danish Ministry of Environment 2003 issued a National Management Plan for the houting, where the problems and possible solutions were identified. It was evident that the main problems were connected to the

Figure 2: Weir at fish farm. Houtings are unable to progress past the fish ladder on right side of the construction.

Figure 3. High quality spawning area with perennial submerged macrophytes.

breeding season in the rivers. Lack of access to the spawning grounds and lack of nursery areas for the young houting during spring gave little or no breeding success, even within the designated Natura 2000 areas.

The plan was followed up in 2005 by an application from the Danish Government to the EU LIFE programme for 60% co-finance of an urgent houting rescue project. In summer 2005, LIFE granted Denmark support of more than € 8 million for the project with a total budget of more than €14 million. The project will be finalized during 2009 and 2010.

Figure 4: High quality nursery area with stagnant waters.

The project is primarily focused on two goals: creating houting access to usable spawning grounds for the adults, and creating new nursery areas for the young fish to grow up in. The project will deliver the following results:

- Demolition of 13 man-made obstacles,
- Renewed access to 137 km spawning area,
- Creation of approx. 30 km of new spawning areas,
- Establishment of 480 ha of new nursery areas,
- Purchase of one netting right,
- 50,000 m^2 new spawning area for salmon

The houting project is the second largest nature restoration project ever in Denmark and the main objective is to restore and maintain a favourable conservation status for the houting in four south-western Jutlandic rivers.

Integrated Coastal Zone Management (ICZM): Status and Prospects

Bastian Schuchardt, BioConsult Schuchardt & Scholle GbR, schuchardt@bioconsult.de

Abstract

The Stade declaration aims at integrated management in the cooperation area and case studies indicate that major sections of the basic ICZM principles have already been implemented by means of the current set of legal instruments. However, implementation is a slow, ongoing process and a number of further adaptations of the legal instruments is necessary. The following are identified as major causes of implementation difficulties: (1) there is still a great lack of clarity on the ways of implementing the ICZM principles; (2) individual actors fear additional restrictions, (3) the distinction from spatial planning is still unclear, (4) the (sectoral) added value is not easy to specify.

Because of the different of legal instruments in the cooperation area, ICZM can be developed and implemented meaningfully in our view only as an overriding demand and as a voluntary, cooperative approach. Spatial planning should be seen as one tool for achieving ICZM. Given the current situation, the following steps, among others, appear necessary:

(1) further optimization of the set of legal instruments according to the basic ICZM principles;

(2) specification of ecological quality objectives, e.g. via WFD, Marine Strategy Directive and Habitats Directive and not via ICZM;

(3) establishment of national ICZM secretariats (or a trilateral secretariat) with high-level political support;

(4) best-practice projects and their evaluation and communication.

1. ICZM process in Europe

Integrated coastal zone management (ICZM) is generally recognized as an important approach for incorporating conservation and sustainable use of marine and coastal biodiversity aspects into the planning process. Therefore, the growing concerns about the deteriorating state of the European coast, environmentally, socio-economically and culturally, have prompted the European Commission and Member States to introduce a range of measures since 1996. The intention is that these will lead to sustainable development of the whole European coast in the future (EU, 1999a).

The first of these was the Commission's Demonstration Programme (EU, 1999b). This three-year programme included 35 individual projects and six thematic studies, embracing the Baltic Sea, North Sea and Atlantic seaboard and the Mediterranean Sea, and was launched in 1996. Based on the results of this programme, the European Commission has subsequently produced two documents on the subject of Integrated Coastal Zone Management. The first of these is a Strategy for Europe concerning the implementation of ICZM throughout the EU coastal states. This 38-point strategy consists of a series of concrete actions building on existing tools, programmes and resources and is a flexible, evolving instrument designed to cope with the specific needs of the different regions and conditions (EU, 1999a). The second document is a recommendation that was called for as the first point of the strategy (EU, 2002).

The European Recommendation on ICZM presents eight principles to guide coastal management in Member States (EU, 2002), including a broad overall perspective (thematic and geographic), a long-term perspective taking into account the precautionary principle, adaptive management based on a sound scientific basis, local specificity, working with natural processes and respecting the carrying capacity of ecosystems, involvement of all partners concerned based on shared responsibility, support and involvement of relevant administrative bodies at national, regional and local level, and use of a combination of instruments. During formulation of the national strategies the Member States should follow the principles to ensure good coastal zone management (EU, 2002). Although critically discussed (e.g. McKennaa *et al.*, 2008), since publication in 2002, the principles have been used by the Member States in developing national strategies in ICZM or at least national reports. In addition, they have become a yardstick for measuring progress in ICZM (ETCTE, 2005).

According to the Recommendation, Member

States are required to undertake a national stocktaking that analyzes which major actors, laws and institutions influence the management of their national coastal zone. In addition, they have to develop a national strategy for the implementation of ICZM based on the results of the stocktaking. These national reports were submitted in 2006. On behalf of the Commission, an external evaluation of these national strategies and reports has been carried out as a cross-border analysis (Ruprecht Consult, 2006). According to this analysis, the status of policy implementation in the 24 EU coastal Member States and Accession Countries is as follows:

- No country has implemented an ICZM National Strategy as prompted by the EU ICZM Recommendation.
- In seven countries, namely Finland, Germany, Malta, Portugal, Spain, Romania and the United Kingdom, implementation of an ICZM National Strategy is pending.
- In six further countries, i.e. Belgium, Cyprus, France, Greece, The Netherlands and Slovenia, documents considered to be equivalent to an ICZM National Strategy have been developed, or coastal zone management strategies have become (or are planned to become) an integral part of their spatial planning processes.
- In eleven countries, namely Bulgaria, Croatia, Denmark, Estonia, Ireland, Italy, Latvia, Lithuania, Poland, Sweden and Turkey, no ICZM equivalent policies are in advanced stages of preparation, only fragmented tools are in place to address coastal issues.

This report was the basis for the Communication on the evaluation of ICZM in Europe (EU, 2007). From our point of view the main statements were as follows:

- Implementation is a slow, ongoing process and more efforts are necessary.
- Interpretations of ICZM vary greatly across Europe.
- Several relevant, more specific instruments have been formulated (e.g. Water Framework Directive).

However, EU ICZM policy should also be considered in the broader framework of the future EU Maritime Policy as outlined in the Blue Book 2007. As the geographical scope of the maritime policy proposed in this Blue Book includes the coastal zones, Integrated Coastal Zone Management has a role to play in the policy framework proposed. The integrated approach to policy-making applied in the future EU Maritime Policy and its environmental pillar, the EU Marine Strategy Framework Directive, as well as the EU directives implemented in recent years will contribute to improving coordination and integration. According to the Communication, no ICZM directive is foreseen at this stage. However, this will be re-evaluated during the coming years.

Overall, the Communication identified only little progress in the implementation of ICZM in the Member States during the last 10 years, and the following are recommended for further promotion of ICZM (EU 2007):

- Implementation (or development) of national ICZM strategies;
- Clarification of the ICZM principles;
- Implementation of the Marine Strategy Framework Directive;
- Strengthening of the regional seas conventions;
- Strategies to adapt to climate change;
- Communication and promotion of good practices regarding ICZM.

2. ICZM in the Wadden Sea region

2,1 Trilateral Cooperation

For more than 25 years, The Netherlands, Germany and Denmark have worked together in conserving the Wadden Sea, one of the world's most important coastal wetlands. Decisions by consecutive governmental conferences have marked several political milestones throughout the years, e.g. the approval of the Trilateral Wadden Sea Plan (1997), and the cooperation can thus be regarded among Europe's "best practice" in cross-border cooperation.

The Wadden Sea Plan embodies:

- a common delimitation of a Wadden Sea Cooperation Area (and Conservation Area);
- a common vision for the Wadden Sea, the guiding principle and the management principles;
- common eco-targets and measures and activities to achieve those targets; and
- implementation of a joint monitoring and assessment programme.

All activities have been coordinated by a common secretariat since 1987. Thus several of the EU ICZM guiding principles have been put into practice in the Trilateral Cooperation Area without calling it ICZM.

At the governmental conferences in 2001 and 2005 the cooperation has, on the one hand, widened its scope from "protection of the natural (cultural) resources" to "sustainable development". At the same time the scope of the cooperation has been strengthened to ensure coordinated and consistent implementation of the EU environmental and nature conservation directives. This shift from "protection" to "sustainable development" indicated, on the one hand, the political willingness to strengthen integrated management. On the other hand, however, this might be understood as a weakening of nature protection if the same organization has to shift its aims in such a way. This means we must be correspondingly aware in future ICZM implementation to avoid such developments.

2.2 Wadden Sea Forum

The Wadden Sea Forum (WSF) was established in 2002, following a decision by the 9th Governmental Conference of the Trilateral Wadden Sea Cooperation. The WSF is an independent platform of stakeholders from the Wadden Sea region consisting of representatives of the Agriculture, Energy, Fisheries, Industry and Harbour, Nature Protection and Tourism sectors, as well as local and regional governments. Among other things, the WSF's mission is to oversee, stimulate, support, facilitate and evaluate implementation of the WSF strategies for sustainable development and to encourage further dialogue between stakeholders in the region.

The Wadden Sea Forum has developed the strategy "Breaking the Ice" (WSF, 2005), including a common vision and a Wadden Sea Region ICZM Strategy. An ICZM working group has been set up to support implementation of the strategy.

2.3 National strategies

As mentioned above, the Member States had to carry out a national stocktaking of management of the coastal zone and, based on this assessment, develop an appropriate national strategy to counteract possible weaknesses and gaps in coastal zone management. For the Wadden Sea, the situation is as follows:

Denmark

A brief ICZM Status Report was submitted in 2006 (Ministry of Environment, 2006). No comprehensive Danish ICZM National Strategy, following the EU ICZM Recommendation, has yet been formulated. Some initial steps were taken up to 2003, when it was decided to effect a major structural reform of the Danish municipal system. A number of initiatives were developed to promote ICZM.

The Danish government perceives the Danish planning system in general as adequate to tackle the challenges of securing a proper balance between conservation and development of the coastal zone. Weaknesses and gaps are dealt with currently by adjusting existing laws, regulations and practices as well as implementing EU directives and policies. In 2003, the Danish government decided to implement a major reform of the regional and local government structure. After this decision the Ministry of Environment decided that it would be more appropriate to postpone a debate on a possible national strategy on ICZM until after 2007 when the reform was to be implemented.

Germany

A national report for ICZM in Germany was submitted to the European Commission as an assessment and steps were taken towards a National ICZM Strategy for Germany (BMU, 2006). The report defines the strategy as an informal and thus voluntary approach, supporting sustainable development of the coastal areas. ICZM is not regarded as a statutory instrument for formal planning and decision-making procedures. The report states that the current legislative framework in Germany is capable of meeting most of the ICZM principles, though further legislative adaptation and optimization of governance instruments are encouraged by the national strategy. Currently, a coordination office is under development.

The Netherlands

The Netherlands submitted a progress report on implementation of the ICZM Recommendation in The Netherlands to the European Commission with the main purpose of showing the extent to which the Dutch coastal zone is managed in an integrated and sustainable manner (RWS/RIKZ, 2006). The Netherlands has decided not to develop a separate strategy for ICZM, but to make use of two existing building blocks which in fact are supported by a variety of complementary statutory institutions: the National Spatial Strategy and the Third Policy Document on Coastal Areas, which provides an integrated framework for coastal zone management and policies on coastal areas.

The result shows that, although different approaches in responding to the Recommendation are pursued in The Netherlands, Germany and Denmark, the basic strategy is similar. All three countries are pursuing the strategy that the current national legislative framework is (more or less) capable of meeting the ICZM principles and that only relatively minor (if any at all) legislative adaptations and optimization of governance instruments are necessary.

2.4 ICZM and project development

The process of project development can bee seen as a good touchstone for the implementation of ICZM. Recently 2 (3) retrospective evaluations of project development and implementation have been reviewed according to ICZM principles.

RETRO

The objective of the interdisciplinary RETRO project supported by the German Federal Ministry for Education and Research (BMBF) was to analyze current practice in planning procedures in terms of their ICZM compatibility by means of a retrospective analysis of 10 large-scale project approval and planning procedures in the German coastal zone so as to be able to provide guidelines for the implementation of ICZM in Germany on this basis (Schuchardt *et al.*, 2004). Since the requirements for "good ICZM practice" have not been adequately specified to date, 17 criteria for "good ICZM practice" have been developed using, in particular, the existing EU ICZM papers as the basis. The focus was on the procedural aspects of negotiation and integration as well as the material aspects of a relative strengthening of ecological sustainability. The criteria have been operationalized through formulation of 55 assessable indicators for "good ICZM practice".

The analysis of planning practice and of the underlying legal tools, which was conducted with an eye to "ICZM compatibility" on the basis of the indicators, showed in a synopsis that the set of planning tools established in the German coastal region meets in part the ICZM demands for negotiation, integration and appropriate consideration of the ecological aspects of sustainability. In view of this background the authors recommended implementation of ICZM in Germany on the basis of the existing legal planning framework.

However, the analysis also revealed substantial deficits deficiencies?. Therefore, for further implementation of ICZM in Germany the authors recommended a number of adaptations and extensions of the planning tools, which are designated as recommendations for action. In addition to the required broadening of the opportunities for participation, the recommendations focus especially on significant strengthening and extension of regional planning in general and of the regional planning procedure in particular. A number of recommendations, such as that for relative reinforcement of the ecological aspect of sustainability and for improvement of territorial integration, also refer beyond planning processes to more fundamental aspects of the governmental and political decision-making system.

WSF ICZM Project

The ICZM working group of the WSF initiated the project "Analysis of ICZM Cases". The objective of the project was to analyze current practice in planning procedures in terms of their ICZM compatibility by means of a retrospective analysis of 8 cases in the coastal zones of NL, D and DK. This was done using the 8 ICZM principles outlined in the EU ICZM Recommendations as a yardstick (WSF, 2008).

Based on this case analysis, a synoptic evaluation has been carried out (Bioconsult 2009). The latter shows that, because of the open formulations in the eight principles, reproducible evaluations of the implementation of ICZM are possible only to a limited extent. The scope for interpretation on the part of the authors is considerable. Nevertheless, the analysis enables an overall assessment of the situation. The results seem to be in line with an analysis of five coastal sample projects in The Netherlands (performed by the University of Utrecht; cited in RWS/RIKZ, 2005). The study revealed that, although the 8 guiding principles of the ICZM Recommendation had not been consciously discussed, they had been observed in practice.

The analysis of planning practice shows in the synopsis (Bioconsult, 2009) that the set of planning tools established in the trilateral coastal region meets in part the ICZM demands. Consequently implementation of ICZM in the three countries should, in the authors' view, be carried out on the basis of the existing legal planning framework. However, the analysis from a trilateral perspective and additional reviewed literature also revealed substantial deficiencies. Therefore, implementation of ICZM in the countries is not possible without a number of adaptations and extensions of the existing planning tools. Some of these necessary adaptations can be carried out through appropriate implementation of the various EU directives.

3. ICZM in the Wadden Sea region: problems and prospects

The analysis reviewed above indicated that ICZM had been initiated in the cooperation area - though not always explicitly mentioned as such - even before national approaches were developed. The analysis of planning practice shows in the synopsis that the set of planning tools established in the trilateral coastal region meets in part the ICZM demands for negotiation, integration and appropriate consideration of the ecological aspects of sustainability.

The analysis mentioned above identified the following as major causes of implementation difficulties: (1) there is still a great lack of clarity on the ways of implementing the ICZM principles; (2) individual actors fear additional restrictions; (3) the distinction from spatial planning is still unclear; (4) the (sectoral) added value is not easy to specify. However, this indicates that additional to high political support of ICZM, best practice projects, including communication of the results, should be initiated.

Because of the different sets of legal instruments in the cooperation area, ICZM can be developed and implemented meaningfully in our view only as an overriding demand and as a voluntary, cooperative approach. Spatial planning should be seen as one tool for achieving ICZM. In our understanding, ICZM should be further developed as an informal approach to supporting sustainable development of coastal zones through good integration, coordination, communication and participation. On the one hand, ICZM is a process that should permeate all planning and decision-planning levels as a guiding principle and, on the other hand, it is a tool applied prior to formal procedures for the purpose of identifying potential development and conflict as well as resolving conflicts.

The central objectives of ICZM are currently rising in importance in view of the increased economic use of the coast and the analysis has shown that implementation of ICZM is a slow process. It is obvious that ICZM needs high-level political support. To obtain such support, it may be useful in the medium term to adopt an ICZM directive if progress does not speed up.

Although major aspects of ICZM in the Wadden Sea region have already become practice, further significant improvements are necessary (Schuchardt *et al.* 2004; WSF 2005, EU 2007, Wille 2009, and above):

- improvement of territorial integration (including onshore and offshore areas);
- better coordination between authorities;
- better participation especially in early project stages;
- lack of formal ecological quality objectives;
- better transboundary management.

4. Recommendations

It can be concluded that formal implementation of the ICZM principles at the national level is less appropriate than development of the set of planning tools already established in the trilateral coastal region. However, implementation of ICZM in the countries is not possible without a number of adaptations and extensions of the existing planning tools and broad political support. To obtain such support, it may be useful in the medium term to adopt an ICZM directive.

In the short term the following activities are recommended:

- Further optimization of the set of legal instruments according to the basic ICZM principles, e.g. strengthening of spatial planning nationally and trilaterally and better participation, especially in early project stages; this must be done primarily on a national level.
- Better coordinated implementation of EU directives such as Water Framework Directive (WFD) and Habitats Directive (HD); this must be done primarily on the trilateral level.
- Specification of ecological quality objectives for strengthening the ecological aspect of sustainable development, e.g. via WFD, HD, Marine Strategy Framework Directive and not via ICZM; this must be done primarily on the trilateral level.
- Improvement of territorial and transboundary integration and management (including onshore and offshore areas); to be done on the national as well as the trilateral level.
- Best-practice projects and their evaluation and communication
- Development of trilateral management plans (e.g. mussel fishery)
- Establishment of national ICZM secretariats (or a trilateral secretariat?) with high-level political support.

Whether development of the CWSS into a trilateral ICZM Secretariat is meaningful must be examined carefully. On the one hand, it already performs part of this function and would be very suitable. On the other hand, shifting the primary objective of the CWSS or trilateral Wadden Sea cooperation from nature protection to integrated management would presumably weaken the ecological component of sustainable development.

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Integrated modelling techniques for a transparent and participative decision support on the coast and in sea

Dietmar Kraft, ICBM, University of Oldenburg, dkraft@icbm.de

1. Introduction

Integrated Coastal Zone Management (ICZM) and Marine Spatial Planning (MSP) represent a demanding process that aims to balance the management of human activities on the coast as well as in the sea adjacent to it. Using ecosystem-based, strategic and holistic approaches, both these procedures endeavour to combine planning and management instruments, and both involve new ap-proaches to optimisation within sustainable development in coastal zones and marine areas (Rupprecht, 2006).

Douvere and Ehler (2009) see MSP as an informal decision-making process, which promotes participatory methods, and improves transparency in decision-making and spatial management. In a public process, the spatial and temporal distribution of human activities are to be analysed and made available for realisation of these very ecological, economic and social objectives, as specified in a political process. Perfecting MSP (and ICZM) with regard to transparency necessitates supplying full information to all stakeholders in-volved. This improvement facilitates openness, predictability, and a readier acceptance and acknowledgement of any plans proposed (Douvere and Ehler, 2009).

Overall, marine and coastal decision-making is a process that includes "data collection, stakeholder consultation and the participatory development of a plan, [and] the subsequent stages of implementation, enforcement, evaluation and revision" (EU, 2009).

By providing a data processing framework, methods and techniques of inte-grated modelling (IM) are able to support decision-making by means of eval-uation of data, integration of knowledge and visualisation of information. Data-storage and visualisation-tools, e.g. geographical information systems (GIS) and data-warehouses (DWH), provide conveniently centralised and thus direct access to data. Moreover, these management tools can produce clear and concise information from complex data by aggregating and consolidating a range of input values. Numerical and/or knowledge-based models can in turn describe systems, backing up understanding of interactions, of dynamics and changes. Models allow forecasts, predicting possible futures, answering "what if" questions and empowering users in dealing with uncertainties (by working, for example, with expert knowledge in order to project scenarios and calculate probabilities). Through technologies such as web-interfaces and via open access to IM-systems, a variety of projected impacts and management options can be shown. Individual users can access these systems and 'play around' with options, checking the differences between scenarios. Thus, transparent information is made possible: information that shows methods, backgrounds and links to details becomes available. Concepts like participatory integrated assessment (PIA) (see Ahlhorn, 2009, and Ahlhorn *et al.*, in this issue) allow the "everyman" to be part of the decision-making process, and they can lead to decisions that are acceptable to a broad base of stakeholders. Provided there is a suitable structure in place, IM can enable participatory, transparent and interactive decisions, which also happen to be supported on a scientific level.

Steps of decision-making

Decision-making in general as well as particularly in this planning and management context can be described as a process consisting of the following main steps:

- Thinking: processing information by collecting and evaluating data and knowledge, aggregating and visualising the information,
- Judging: forming opinion by evaluating scenarios, possible futures and predictable impacts and estimating probable results of measures taken,
- Selecting: carefully choosing the option that best meets the goals of the planning idea.

Given that decision-making for sustainable planning and managing processes is understood as an ongoing procedure, a relevant fourth step should be:

- Learning: heeding the lessons of the various evaluation and decision-making processes in order to refine and improve these processes and implement wider awareness.

Together, these four steps encapsulate the informal parts of spatial planning as well as the formal approval procedure; overall, they can provide a decision-making framework that is underpinned by IM.

2. Using integrated models for decision support

Integrated Modelling can be seen as a hybrid data processing technique that joins software technology, data interfaces and evaluation tools, computer models and expert systems together into an integrated whole. Below, several examples of IM-tools that support decisions made in the context of ICZM and MSP are given, and their benefits to participation and to transparency in ac-cordance with the four above-named decision-making steps are briefly dis-cussed.

2.1 Processing information: accessing data

Collecting the data and knowledge necessary for making the required decision relies on methods that (technically) manage information sources such as data-bases, geographical information sys-tems and data-warehouses. These systems provide tools for accessing the relevant data, and furnish techniques for pool-ing and typifying data (and knowledge) and for making the significant results visible. The use of maps as a format to illustrate results allows pieces of data to be linked in relation to their spatial positions. Techniques such as GIS should no longer be the domain of experts: they should be made accessible, preferably online, and usable by laymen. Figure 1 shows a screenshot of a Web-GIS-model. Systems like this, easy to access and transparent, allow stakeholders to call up the information they need.

2.2Forming opinions: computing scenarios

Based on this collated information, models can predict the possible conse-quences of an in-tended management decision. Modern modelling techniques are able to take expert knowledge into account: they can employ GIS to inte-grate the various levels of the system being assessed and can analyse interde-pendencies according to spatial position, in order to make their predictions spatially explicit. Combining different objectives such as ecosystem functions, nature protection, land uses, infrastructures and/or recreational facilities is a challenge for integrated modelling (Eppink, van den Bergh *et al.*, 2004; Evers, 2008; Jopp and Reuter, 2008). Modern data models and interfaces can be used to merge the information, but scales, dimensions and the relative weight of the individual information displayed remain the crucial factors. Calibration of the "significance" of the parameters within an integrated model re-quires a good deal of expert knowledge, especially as resilient data is predominantly absent. In order to remain participatory, the operations that con-nect the various sub-systems of the model being

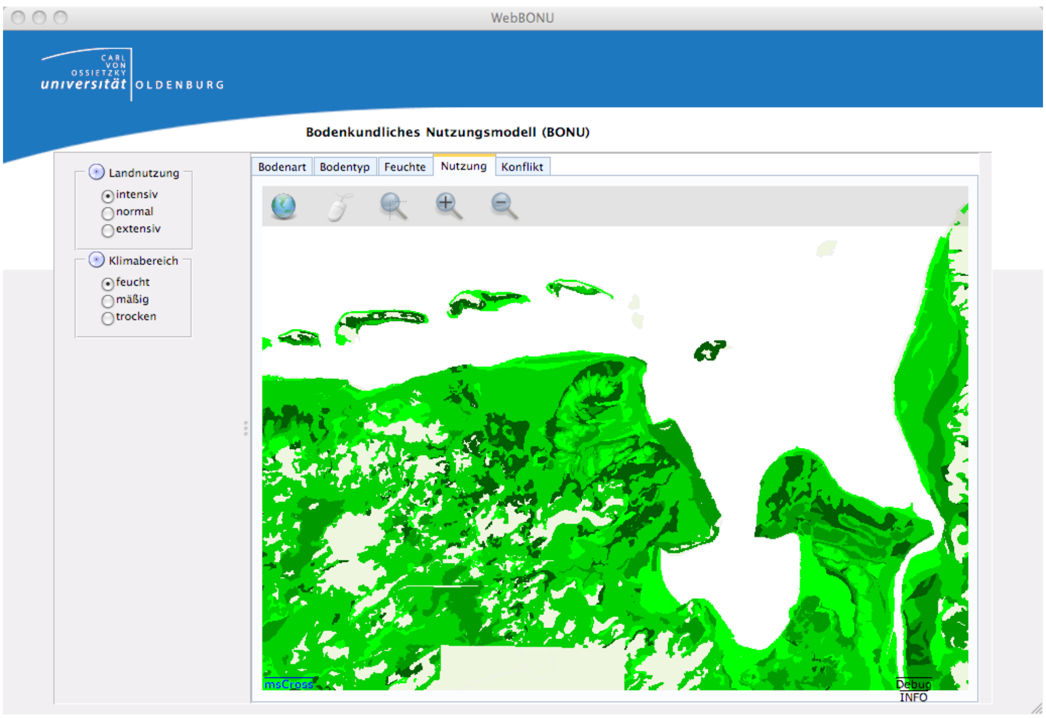

Figure 1: Web-GIS-model BONU: a rule-based soil-science-model, aggregated on the level of soil-types and habitat-types respectively, predicting impacts of cli-mate and land-use changes (Kraft, 2004).

integrated have to be transparent, accessible, and easily alterable (see Figure 1). And they should, of course, be discussed with the stakeholders concerned.

2.3 Choosing carefully: reviewing options

Selection of the right option from the different possible outcomes that are projected by integrated models appears to be the most important step in the decision making process. Although IM can support the process with information about the probable benefits and possible impacts of a decision, stakeholders (and, ultimately, the executive authority) have to compare the options and decide on the action to be taken. IM provides a technical framework that combines methods of evaluation and analysis in order to simulate the negotiation process, for instance in a multi-agent system. The separate methods constitute different approaches to reviewing the options that are "competing" to ascertain which decision is appropriate. Fig. 1 shows the modelled damage potential resulting from an oil-spill in comparison with the possible towing directions for shipping resulting from a simulated negotiation process. Liu (2006) developed this approach as part of an IM-framework that simulates the management of oil-spills online.

2.4 Learning: find out participation

The complexity of environmental decision-making provides an opportunity to enhance social learning. The challenges that emerge from environmental planning, global climate change, for example, and changes in the legal framework, have led to a shift in federal activities as well as a strengthening of the role of stakeholders (Rupprecht, 2006; Bruns and Gee, 2009). Active involvement in the decision making process promotes the development of individual competence, heightens self-esteem and builds respect for the indi-vidual competencies of others. Participatory approaches like PIA allow a per-sonal negotiation process, by enabling stakeholders to become actively in-volved in the decision making process. Integrating such methods in a frame-work with first-hand and interactive access is one of the facets of IM; social learning appears to be one of the possible outcomes.

3. Conclusions

Integrated Modelling as illustrated here is a sophisticated scientific approach that links information, knowledge and the management methods that regulate human activities on the coast and at sea together holistically, in an ecosystem-oriented way. Since it supports the decision making process by processing and analysing data, judging scenarios and selecting options, and, finally, by mak-ing social learning possible, IM can provide a framework for deciding on the right steps to take towards a sustainable planning process. Even when struc-tured within a conceptual model, the continual management procedures of MSP and ICZM remain transparent and participatory, as long as an open – i.e., online – access to information and knowledge is provided for everyone; inter-faces have to encourage stakeholders to contribute their know-how and their needs at each crucial stage of the decision-making process.

Integrated Modelling makes a range of methods available that can support decision-making. The IM-framework allows stakeholder, decision maker, general public and local government alike to gain access to the necessary knowledge; it brings participants together, allowing all of them to be part of the process, and, in the end, validate the way the decision was made. To un-derstand and to accept the approach, and to make it sustainable, each stake-holder has in some way to be part of the entire decision process. The examples given not only illustrate the success of attempts at demonstrating the suit-ability of integrated modelling methods to support a decision-process, but also describe the considerable effort involved in enabling integration in the choices made.

Although the importance of transparency and participation are beyond dispute and the overall benefit of a joint data basis is universally accepted, the acces-sibility of information is still rather disappointing. While local authorities es-pecially give simple and open access to reprocessed data (via, e.g., web-services), gaining access to raw data as input for models is still difficult and complex. Access rights, ownership and areas of responsibility are an annoying bottleneck to gaining information access. Furthermore, communication, espe-cially between different sectors, has remained frustratingly poor: within the scope of ICZM and MSP, active institutions, the scientific community and the proper authorities seem often blissfully unaware of each other: the network is not a consolidated one. Additionally, stakeholders in these processes still have to be motivated into becoming actively involved. In particular, the potential of online access to databases, GIS and models should be more fully utilised, as they enable users to select their own scenarios, their own interrelationships and their own options, and to reflect them in the system. The use of new tech-nologies such as Web 2.0 to integrate science, technology and decision-making as resources that lead to sustainable management of the coastline and the sea adjacent to it can be seen as a social challenge and, potentially, a stimulus to science.

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What *have* we done? Mapping the historic cultural processes that shape our coastal and marine environment

Dave Hooley, Characterisation Team, English Heritage, dave.hooley@english-heritage.org.uk

1. Background and context

It is generally understood that present expressions of our coastal and marine environment are outcomes from cumulative impacts of human cultural activity on natural processes over thousands of years. Strengthening evidence emphasises the unsustainability of later stages in that long relationship, with serious environmental, particularly ecological and climatic, implications already identified and trends indicating more severe imminent consequences. A key difficulty in addressing this has been poor coverage and coordination of controls over human activities affecting the marine environment: usually sectoral where they exist and difficult to enforce both legally and physically. Compounding that are poorly developed popular perceptions and understanding about how our societies use and impact upon the marine environment. This level of ignorance in the cultural context has allowed a continuation of environmentally destructive or damaging activities on scales long prohibited or subject to tight control in the more visible land-based contexts with which people do identify.

Since the mid-1990s, governments at EU and national levels have responded, seeking better understanding of coastal and marine environments and their processes to underpin more strategic integrated planning and management. This period also saw rapid growth on land in forward looking, plan-led, spatial planning facilitated by technological developments, especially in Geographic Information Systems (GIS), which have hugely enhanced our ability to collect, manipulate and present complex spatial data. These trends have combined to give clear momentum in policy development for the sustainable use of the seas and conservation of marine ecosystems through integrated, coordinated management of our activities. Chief outcomes at European Union level are the Integrated Maritime Policy (EC, 2007a) and its environmental pillar, the Marine Strategy Framework Directive (EU, 2008).

The EU Integrated Maritime Policy, with its Action Plan (EC, 2007b), seeks the fully integrated, inter-sectoral, coordination of economic, social and environmental aspects of maritime activity, recognising maritime spatial planning and ICZM as fundamental to achieving sustainable development and the commitments of the Marine Strategy Framework Directive. A subsequent roadmap aims for common principles for maritime spatial planning across the EU (EC, 2008). Similar principles and measures underpin national coastal and marine policy in some Member States, notably the UK (Defra, 2005, 2008; UK Government, 2009).

2. The relevance of historic cultural understanding

Beyond the needs for decision-making to rest on data-availability for a wide range of human activity (EC, 2007a, 3.2.3) and the importance of achieving socio-economic sustainability within the Policy's overall objectives (*ibid.*, 4.1), EU Maritime Policy specifically emphasises its measures' relevance to the quality of life of coastal communities and the need to reconcile that with environmental sustainability (*ibid.*, 4.3). The point is clear. Achieving sustainability in human activity is far more than a purely environmental issue: it is essentially cultural too. Certainly man is a major ecological force, but also a highly cultural animal. What we do and how we act, now as in the past, are governed by how we think, understand and perceive the environment: perceptions in which our senses are coloured by our own experience and the cultural milieu we inhabit. Those perceptions build cultural identities in which distinctiveness plays a strong role, with multitudes of expressions in our attachments, for example, to particular place, dress, morality, or ways of behaving. Long term environmental sustainability needs to correspond with a sustainable cultural context supporting it. Not only to ensure public accountability for our spatial planning systems, though that is clearly important, but more broadly to ensure our sustainable realignment of coastal and marine activities enjoys the willing support and participation of those whose perceptions and identity it affects (Hooley, 2007). That need for cultural engagement lies at the heart of the European Landscape Convention (Fairclough, 2007a, 2007b), in force in the Netherlands, Denmark and the UK.

It is also recognised in the Trilateral Wadden Sea Plan's 'Landscape and Culture' target 'to pay special attention to the environmental perception of the landscape and the cultural-historic contributions in the context of management and planning' (Enemark, 2006). Cultural connectivity between people and the environment is integral to sustainable management. As noted above, lack of that connectivity has helped perpetuate ineffective control over damaging marine activities long regulated more rigorously on land.

Landscape itself is a cultural artefact, the product of interacting cultural and natural processes. It relates to the typical and the present but it is also a matter of perception and understanding: we can only understand the variation and environmental implications of its distinctive character when we bring to bear our knowledge of the forms and time-depth of the cultural processes which have produced it. Significantly, landscape is comprehensive, spatial and of the present, offering an effective vehicle by which baseline information on cultural variation and distinctiveness can inform spatial planning. Landscape is both culturally produced and culturally perceived by people today. It is present everywhere, relevant to the quality of life and identity of us all, whether or not we are interested in the historic cultural processes that have shaped the familiar in each of our minds. But of particular relevance, landscape itself is characterised by change. Landscape is varied and distinctive precisely because it embodies change, whether slow or rapid. As human society, viewpoints, activity and impacts always develop and change, so too landscape is always transitory with no original and no completed form. That gives a valuable perspective for framing the changes inevitable in re-aligning man's relationship with the environment to one of sustainability.

Other historic cultural aspects have relevance too. Understanding the time-depth and character of human cultural processes that have shaped our present environment and its ecosystems is critical to inform targeting for future sustainability under the ecosystem approach. Much ongoing research emphasises impacts from recent industrial-scale activities and the climatic and chemical changes occurring on a global scale, but current ecological statuses also reflect massive cultural impacts over many decades, centuries and millennia. The decimation of Newfoundland cod stocks by the end of the 1980s and their subsequent failure to recover (Rice *et al.*, 2003) is only a recent chapter in a long history of over-fishing whose repercussions throughout the ecosystem need building into our consideration of what constitutes a healthy sustainable ecosystem for our management policies to aim for. But impacts from man's activities are much broader. Most coastal and estuarine margins have long been intensively managed with hard defining boundaries, leading in some cases to coastal squeeze (Jones, 2001), while sediment supply along coasts has been considerably modified by groynes and breakwaters. Vast amounts of sediment brought downslope by millennia of agriculture have had enormous geomorphological impact, filling valleys and, where they meet the sea, altering estuarine conditions. Similarly, coastal land reclamation has been widespread where the topography offered the opportunity, impacting hugely on ecological communities peculiar to such topographic circumstances. A cultural understanding also holds direct positive benefits for sustainability planning. Some surviving methods of coastal and marine resource exploitation have long backgrounds offering clues to future long-term viable relationships with opportunities to incorporate existing aspects of Europe's diverse coastal and marine cultural heritage in a more sustainable future. Analyses of buying habits and marketing trends may reveal opportunities to promote economic viability for more sustainable culturally-distinctive activities; trends such as the increasing popularity of localism in food production and consumer preferences for short distribution networks.

3. Bringing historic cultural character to sustainable planning

One session theme at the Wadden Sea Symposium 2009 queried how we close the current gap in the consideration of cultural aspects in sustainable coastal and marine management. As noted by EU Maritime Policy (EC, 2007a 3.2.3), spatial planning is most effectively informed by data presented in map-based formats, with comprehensive coverage and in a manner interoperable with other databases. Good progress has been achieved in those respects for many physical and ecological aspects of the marine and coastal environment. By contrast, progress has been slow in bringing understanding of our cultural dimension to equivalent interoperable, area-based formats. Most cultural databases take a selective view of our heritage, emphasising known distributions of the rare or 'special' in our past material culture, often seen as the most significant and the focus of statutory designation. Such approaches will always be extremely valuable in targeting conservation efforts but they have considerable drawbacks for informing spatial planning in the cultural context behind the present. Being selective, they lack comprehensive coverage, their elements appearing as point data against base-mapping and lacking full interoperability with other, GIS-based, environmental mapping. The point distribution has only indirect relationships with the past: it records locations and findspots of past material remains, but its patterning reflects where later or current activity has revealed such remains or left them exposed. Rather than mapping activity contemporary with those remains, it often reveals patterns of recent fieldworkers' activity and ground disturbance. But especially problematic, it focusses on the atypical rather than typical cultural processes which have made all present places culturally distinctive to our perceptions. It focusses on material fragments from the past rather than comprehensive time-depth in the present, overlooking the cultural inheritance embodied by areas between those fragments: our present landscape.

4. Historic landscape and historic seascape characterisation

The 1990s saw a rapid growth of spatial planning in the UK along with the application of characterisation approaches to a range of environmental and landscape-focussed themes, for example Landscape Character Assessment (Countryside Agency & Scottish Natural Heritage, 2002). To ensure these can take account of the formative role of historic cultural processes in shaping their respective themes, English Heritage initiated a programme of 'Historic Landscape Characterisation' (HLC). Its map-based format and use of GIS make HLC particularly effective in informing spatial planning, filling that gap in the provision of cultural information interoperable with other GIS-based environmental datasets. HLC provides largely neutral, baseline information which enhances understanding and debate with a generalised statement of historic character, relevant to a range of planning, conservation and management-led initiatives (Clark *et al.*, 2004). HLC is designed to inform the management of change in the whole environment, whether historic or natural, and focuses on the character of the typical and on time-depth in the *present* landscape, not a reconstruction of past landscapes. The present landscape is the only one we can perceive experientially and know in its entirety. It is also the landscape in which change happens which will shape the future. That is critically important to the aim of cultural sustainability lying at the heart of HLC: to guide the management of change so that we pass on the cultural landscape legibility we have inherited, enabling future generations to build *their* identities, sense of place and meaning from *their* landscape.

Complementing other landscape and environmental characterisations, HLC creates a comprehensive, generalised and descriptive understanding of the cultural and historic character of an area or topic. Using a methodology pioneered in Cornwall in 1994 (Herring, 1998), it brings together existing, often previously uncorrelated information to portray a broad understanding of the typical and dominant characteristics of the historic environment. HLC accords all 'Character Types' equal treatment and value, standing back from selective and time-specific attribution of significance and recognising the need for judgements of value and significance to be defined and applied at the time and context of particular applications. Comparing HLC databases with others' perceptions of the same landscape gives opportunities to build understanding from many different perspectives, informing and incorporating public perceptions as well as expert-led specialist approaches. So HLC may be seen as a process as well as a product: a starting point for understanding, dialogue and decision-making. Indeed that is how HLC is already being used in its many current and developing applications in England (Clark *et al.*, 2004; Fairclough, 2002; 2007a, b; http://www.english-heritage.org.uk/characterisation).

Coastal and marine contexts provide the same strong motivations as on land for applying characterisation approaches to bring a historic cultural understanding to our sustainability planning. EU responses to needs for radical reform of our management of the seas were closely mirrored in the UK. The UK state of the seas report, Charting Progress (Defra, 2005), emphasised needs for more consistent, better integrated methods of data gathering, storage, presentation and management, while the Marine and Coastal Access Act 2009 will, once fully implemented, introduce a forward-looking, integrated, plan-led marine spatial planning system to UK Controlled Waters (UK Government, 2009a). The UK Government has already published high level marine objectives to underpin the first Marine Policy Statement (UK Government, 2009b), explicitly recognising the need to maintain the diversity of seascape character around our coastline (*ibid.*, 5) and the roles of seascape and the marine environment's cultural heritage in ensuring a strong, healthy and just society (*ibid.*, 6).

In 2002, English Heritage's remit was extended to the limit of the UK Territorial Sea. Responding to its new responsibilities and increasing requests for historic environment inputs to SEAs relevant to the limit of UK Controlled Waters, English Heritage undertook the England's Historic Seascapes Programme from 2004-2008, commissioning five substantial pilot projects to develop, test and refine various approaches by which HLC principles could be expressed effectively in coastal and marine contexts: Historic Seascape Characterisation (HSC) (Hooley, 2004, 2007). With obligations to apply their method development *inter alia* to the practical test-bed of contextualising application responses for marine aggregates extraction and emphasising their methods' relevance to future sustainable management, the Programme was funded by England's 'Aggregates Levy Sustainability Fund' (ALSF) (Newell & Garner, 2007, 98-113; Newell & Measures, 2008, Chapter 12). The pilot projects spanned a broad range of environmental and management circumstances around England's coast and seas to ensure that, as with HLC, the developed HSC method would be robust and give baseline information relevant to a breadth of applications. Experience from the pilot projects was reviewed and consolidated as a national HSC methodology in March 2008 (Tapper, 2008), its Method Statement was published on the Archaeological Data Service website (*ibid*, http://ads.ahds.ac.uk/catalogue/archive/seascapes_eh_2008/downloads.cfm). That method is now being implemented around England's coasts and seas.

Extending the principles underpinning HLC to our coasts and seas involved considerable challenges. On land, historic processes mostly impact on a relatively thin surface veneer while in the marine environment they are expressed across a layered three-dimensionality with complex spatial relationships between those layers in terms of process, activities and impacts. To ensure it is responsive to user needs and applications, HSC provides separate characterisation of each major tier of the marine environment (the sea surface, water column, seafloor and sub-seafloor), each in terms of its present historic cultural character plus provision to map multiple expressions of previous character in any area with evidence for it. There is also provision to map dominant character across all marine tiers: a conflated HSC map (Figure 1).

The marine and much of the coastal zone lacks the comprehensive fine network of mapped fixed boundaries by which historic character is usually portrayed on our well-mapped land surface. Creating its own mapping framework, HSC characterisation below Mean Low Water (MLW) is held in the cells of a fine vector grid mesh, while above MLW it is held by polygons in the same manner as in HLC. The marine environment also

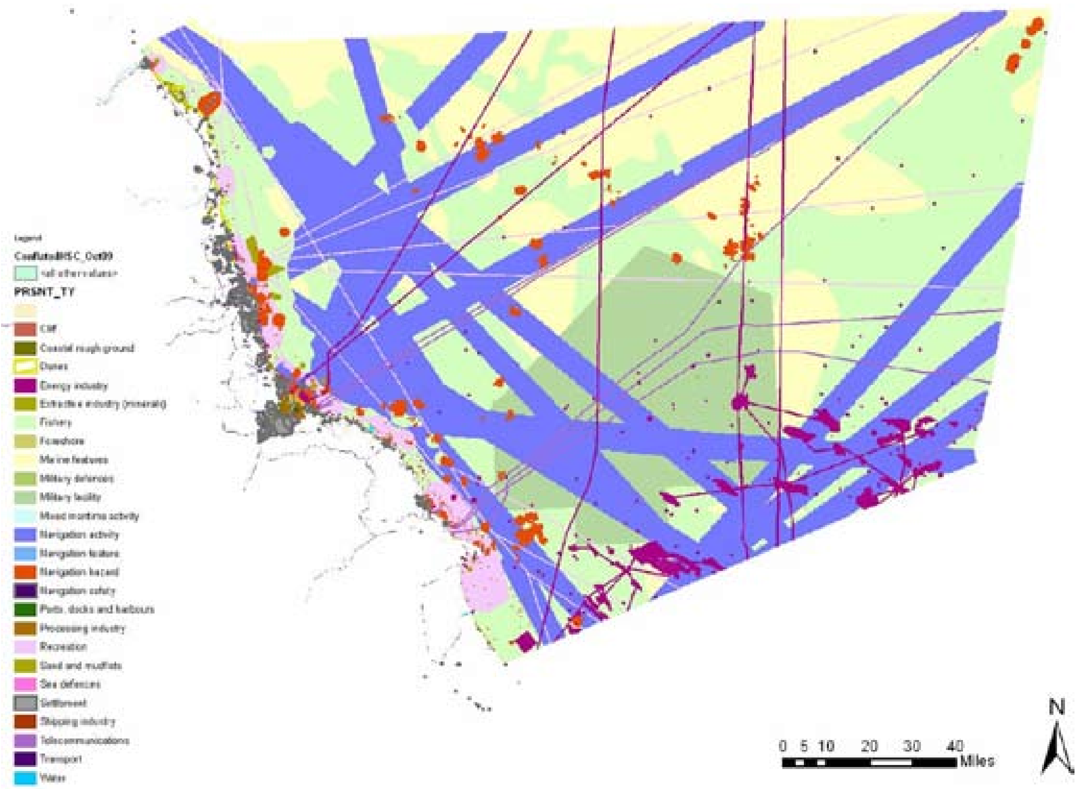

Figure 1: Conflated HSC mapping of England's north east coast and seas, from the Scottish border to Holderness © English Heritage.

provides a very different basis from land for our landscape perceptions. On land, we *sense* historic landscapes primarily visually but only *perceive* them as 'historic landscapes' when we inform that sensory data with our cognitive data: applying and extrapolating what we have learned or experienced from a variety of sources, historical and archaeological amongst many others. Similar principles apply to marine contexts. Historic processes and their impacts have certainly occurred, and still occur, widely across all layers of the marine environment but with marked differences from land in their presentation to our senses of the relationships between the sensory and the cognitive. Attempting a simple analogy with perception on land and using direct visual sensation of the marine environment to dominate our marine landscape perceptions, we view the sea surface in the present, a canvas on which impacts from the long history of human marine and maritime activity is generally not written. Visual impact assessment of that relatively bland present sea surface does have a valuable role in managing change but it views the sea largely as an adjunct to the land. It does not focus on the varying distinctive character of the marine historic environment itself or allow it to inform our landscape perceptions of the sea in the manner we expect for landscapes on land. Historic seascape characterisation cannot rest mainly on direct visual sensation: cognitive data will always dominate our historic seascape perceptions. Submerged aspects of the sea may be invisible at landscape scale but play major roles in shaping our seascape perceptions when brought to bear through our knowledge, as cognitive data. This is clear in the wreath-laying ceremonies commemorating maritime disasters or naval battles: seemingly innocuous stretches of sea surface are given powerful meaning by the participants' knowledge of their historic cultural associations.

The coastal relationship between HLC and HSC is one of overlap, not abutment, to match the overlap in our terrestrial and maritime perspectives. Sharing common principles across land, coast and sea, HLC and HSC are well-placed to inform decision-making and support other themes of landscape character assessment spanning the entirety of the coastal zone: both a seamless continuum and an area of overlapping landward and seaward perspectives and perceptions. Such common frameworks of understanding have been long recognised as essential to meet pressures and requirements for integrated, comprehensive and sustainable coastal management (Fulford *et al.*, 1997, 18, 226-7; EC, 2002; Defra, 2008).

Accompanying the HSC GIS database, consistently structured, jargon-free, explanatory texts describe the HSC 'Character Types', enabling other specialists and all involved in coastal and marine planning to engage easily with HSC's perspective. Supplemented with imagery, their readily-assimilable content and language makes them suitable as a web resource to convey the HSC perspective of seascapes to a wider public, raising awareness and prompting thought, dialogue and debate. The web resources and other reports prepared by most of the England's Historic Seascapes Programme pilot projects are publicly available on the Archaeological Data Service (ADS) website: http://ads.ahds.ac.uk/catalogue/projArch/alsf/seascapes.cfm. Future HSC projects funded by English Heritage will produce similar web-enabled resources.

English Heritage has begun to implement the HSC method around England's coasts and seas, contributing, project by project, to an English national HSC database http://www.english-heritage.org.uk/server/show/nav.8684. Also funded through the ALSF, an initial project from October 2008 extends from England's north east coast to where UK Controlled Waters meet those of the Netherlands and Germany. A further five large HSC projects will encompass approximately 75% of England's coastline and adjacent UK Controlled Waters by March 2011.

5. Concluding comments

Our coastal and marine environment is subject to many overlapping and competing perceptions and interests which spatial planning at EU and national levels is designed to integrate in the cause of sustainable management. That sustainability obviously needs underpinning by the sound understanding of environmental relationships and parameters embodied by the ecosystem approach, But sustainability is also about how people perceive and relate to the environment, how they value it and choose to behave towards it. Achieving a cultural consensus to correspond with environmental sustainability cannot be done from ignorance or by legal requirement: it requires an aware and informed public. Communities and interests at all levels, from particular localities to large regions, have distinctive perspectives, opinions, approvals and concerns about activities that impact on the familiar, whether negatively or positively, well-regarded or not. HLC and HSC help place such positions and challenges in broader context, allowing debate about the present and future to be grounded in an understanding of the historic cultural processes that have shaped the present (Hooley 2007, 2009). HLC and HSC are products and a process expressly designed to facilitate discussion and dialogue about the culturally sustainable management of the land, coastal and marine environment as a whole.

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Long-term perspectives in coastal zone development – A participatory assessment process

Frank Ahlhorn*, Jürgen Meyerdirks#, Thomas Klenke*
*Centre for Environment and Sustainability Research (COAST), University Oldenburg, ahlhorn@icbm.de
#Institute for Chemistry and Biology of the Marine Environment (ICBM), University Oldenburg

Abstract

Public participation is recognized at international and national levels to be one of the pillars of sustainable development. Especially in coastal regions, different types of land use coincide with varying interests and needs, which leads to multifaceted conflicts. In Lower Saxony (north-western part of Germany) with a large flood-prone area, the most important land use is coastal protection. Over the last decades the protection against flooding was based on a single line. Nowadays, taking into account the likely impacts of climate change, coastal protection has to face new challenges. New concepts to meet these challenges are the application of spatial protection concepts. The spatial demand for coastal protection conflicts with other types of land use, especially in the Wadden Sea Region. Several conflict resolution approaches were applied to react to urgent coastal land use conflicts. The application of participation processes to prevent land use conflicts or even to create solutions for anticipated future conflicts were difficult to find. Therefore, new approaches are needed to consider and to integrate coastal protection into spatial planning to provide the opportunity for sustainable coastal development. In this article a pilot study will be described and discussed where a participatory integrated assessment process was applied to provide a basis for jointly created innovative land use management. The participation process is elaborated in the multi-faceted way it appears by the progressive approach of stakeholder engagement from the very beginning. This process was a coming together of methods from wide participation and socio-economic evaluation.

1. Coastal protection strategies in the southern North Sea region

The flood-prone area of the southern North Sea region is approximately 40,000 km² with 12 million inhabitants (Doody *et al.*, 2004). Although there was always a high risk of winter flooding, the flood plain was populated centuries ago and the settlers had started to protect themselves against storm surges by building embankments. Initially, they had built dwelling mounds followed by ring-dikes to enclose their farm land. As a result, a single line of defence protects the current floodplain of several countries in the southern North Sea. A short line of defence could be cheaper to maintain and the improvement of a single line might be more cost effective. Since the disastrous storm surges in the last century in the Netherlands and Germany, the strategy of reactive coastal protection strategies was changed by the introduction of technical measurements, such as the design water level and design waver run-up. The engineers try to anticipate the future physical load on the single line of defence by the introduction of these measurements. The growing environmental movement in the 1970s has led to the consideration of ecological aspects in coastal protection projects. The Ley Bay project was a prominent example on the Lower Saxonian coast for the influence of this movement (Hartung, 1983; Janssen, 1992). The original plans for the complete enclosure of Ley Bay were revised and the nature reserve of mud and sand was created. This was the result of a lengthy discussion process about different types of land use such as nature conservation, water management and coastal protection (Kunz, 1993, 1999). The latest successful mediation process between the diverging interests and needs in Lower Saxony was conducted ten years ago for improved management of coastal protection projects (NLÖ, 2000). This process was the consequence of a conflict between nature conservation and coastal protection about the improvement of a main dike at Jade Bay. The raising and strengthening of this main dike required the extension of the dike foot. Because of the existing village on the land side the dike foot had to be extended seaward. The salt marshes in front of the main dike are protected within the Wadden Sea National Park of Lower Saxony and the construction of dikes has been prohibited in these protected areas since the establishment of the National Park in 1986. Another example for conflict resolution between nature conservation and coastal protection with regard to the management of salt marshes is the foreland management plan for the dike board Norden (East Frisia, NLWK, 2003). This paper provides a short description of a participation and evaluation process which minimises conflicts and offers the opportunity for joint coastal management. A detailed description of the process and the results can be found in Ahlhorn (2009).

At the Earth Summit in 1992, the concept of sustainable development was introduced which demands a balanced consideration of ecological, economic and social aspects. The emerging interests and needs in space and time in coastal zones over the last decades led to various land use conflicts, especially between nature conservation and coastal protection (see e.g. Heydemann, 1987; Ahlhorn and Kunz, 2002). Simultaneously, the concept of Integrated Coastal Zone Management (ICZM) had been introduced in chapter 17 of the UN declaration on sustainable development (UN, 1992). These concepts emphasise the role of public participation in planning and management. Within the spatial planning plans and programmes at federal state and at a regional level, coastal protection is considered as a sectoral plan without spatial requirements. Currently, the traditional improvement of the single line of defence has to face various challenges, because more space and more building material are needed for higher dikes. On the other hand, the likely impacts of climate change, e.g. sea level rise and the increase of storminess, will increase the physical pressures on the single line of defence.

2. Integrated planning and spatial coastal protection concepts

The demand for integrated thinking has been emphasised in many publications, e.g. Post and Lundin (1996), EC (2002), UNESCO (2003), UNESCO (2006). The definition given in Post and Lundin (1996) for ICZM is most appropriate for this paper: "ICZM is a process of governance and consists of the legal and institutional framework necessary to ensure that development and management plans for coastal zones are integrated with environmental (including social) goals and are made with the participation of those affected. The purpose of ICZM is to maximise the benefits provided by the coastal zone and to minimise the conflicts and harmful effects of activities upon each other, on resources and on the environment".

Obviously, with the beginning of ICZM a new way of thinking was required. The traditional sectoral approach of planning and management has to be replaced by integrated planning and management. The areas of jurisdiction of plans and programmes have to be revised, and the re-active and mainly static approach of spatial planning has to be transformed into a pro-active and dynamic process. This requires adequate and appropriate methods, tools and instruments for both planning and management. Within the last decades, numerous research projects dealt with these issues and developed several methods and tools. It took about 10 years after the Earth Summit for the European Commission to publish the EU recommendations on ICZM (EC, 2002), and the Member States need far more time to develop and implement national ICZM strategies (e.g. BMU, 2006) which did not fully exploit the opportunities of the ICZM recommendations (Rupprecht Consult, 2006).

In particular, the EU Interreg project NORCOAST exercised a strong influence on the development of the ICZM recommendations by the EU (NORCOAST, 2000). The project's aims were to investigate and to promote good practice in ICZM. NORCOAST was based on the experiences and knowledge of practitioners in spatial planning and management on a regional level throughout Europe. Thus, the recommendations of the NORCOAST project focus mainly on the integration of spatial planning into ICZM and what this entails. Some of these recommendations have been taken into account and tackled in the EU Interreg IIIB project ComCoast (*Com*bined Functions in *Coast*al Defence Zones). NORCOAST developed its recommendations on the basis of existing coastal problems around the North Sea. All relevant types of land use were taken into account and recommendations were also made for specific issues such as sea level rise and coastal protection. For these, the main recommendations are as follows:

- Identify areas which may be subject to future flooding and erosion as a result of sea level rise and take these into account in developing spatial planning policies;
- Financial provision for coastal protection should allow for compensation for planned loss of property and land in managed retreat scenarios;
- Provide integrated national and regional strategies for coastal protection planning with adequate national funding in support of regional works.

Within the ComCoast framework the approach of multifunctional coastal protection zones has been investigated in line with the recommendations of the NORCOAST project and latterly of the EU on ICZM. Five spatial coastal protection concepts have been proposed such as regulated tidal

Proposed Solution	Basic Requirement
Regulated Tidal Exchange (RTE)	Appropriate elevation and second embankment in the hinterland or rising hinterland
Managed Realignment (MR)	Appropriate elevation and second embankment in the hinterland or rising hinterland
Overtopping Defence (OD)	Second embankment in the hinterland or rising hinterland
Foreland Protection (FP)	Appropriate width of the foreland and appropriate hydrodynamic conditions
Foreshore Recharge (FR)	Appropriate hydrodynamic conditions

Table 1: Basic requirements for the proposed solutions for the implementation of Multifunctional Coastal Protection Zones, source: Ahlhorn *et al.* (2007).

exchange, managed retreat or an overtopping resistant defence. These spatial concepts, combined with adapted utilisation of the area behind or in between the embankments, will provide benefit for different types of land uses. For example, the benefits of the managed realignment (MR) concept for fish stocks have been discussed during the Wadden Sea Symposium and are explained in detail in these proceedings (Steve Colclough *et al.*, 2010). The feasibility of the implementation of these spatial coastal protection concepts depends on the topography and additional factors, such as erosion in front of the embankments. This varies from country to country around the Wadden Sea Region, but the basic requirements for these spatial concepts are shown in Table 1.

In general, the benefits of the implementation of multifunctional coastal protection zones vary with the applied spatial protection concept. For example, one problem of the 1962 storm surge was that the inner slope of the main dike failed because of wave overtopping. The strengthening of the inner slope with, e.g. geo-textile, allows more wave overtopping and, thus leads to a lower probability of failure (ComCoast, 2007). The implementation of this concept demands the adaptation of the existing types of land use behind the single line of defence. So, the question is how to implement multifunctional coastal protection zones in the coastal zone?

The next section will briefly describe the participation process used for the implementation of multifunctional coastal protection zones in Lower Saxony. With the latest amendment of the Spatial Planning Programme of Lower Saxony in 2008, the preconditions on the Federal State level with respect to spatial planning was given (ML, 2008). On the other hand, the implementation of spatial coastal protection concepts requires a change to the risk management approach in coastal protection. This paper will focus on the participation process and not on the risk management approach - for the latter issue see e.g. Oumeraci and Kortenhaus (2002) and Kunz (2004, 2005).

3. Implementation of spatial coastal protection concepts in the Wadden Sea region

The implementation of multifunctional coastal protection zones has been investigated by a fictitious planning exercise in the north-western part of Lower Saxony. The pilot area is located near the village of Nessmersiel in East Frisia and consists of a broad salt marsh, a summer polder and the polders lying between the main dike and the older dike line in the hinterland (Figure 1). The salt marshes and the summer polder are protected by the National Park. The polders are mainly used for intensive farming.

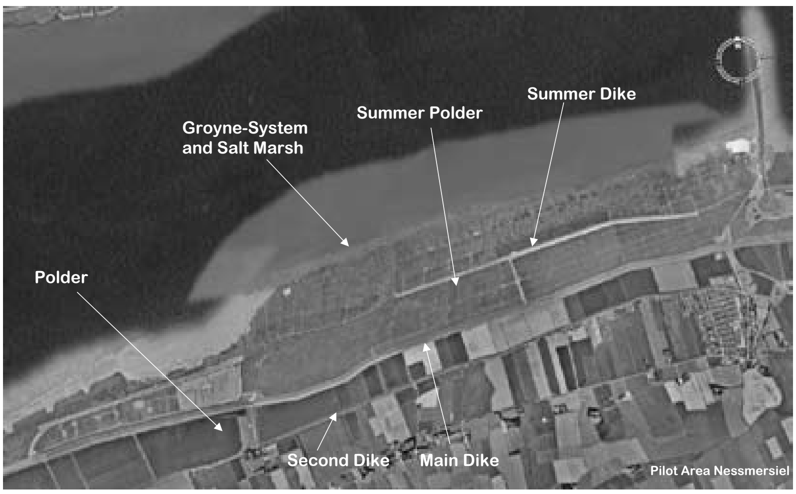

Figure 1: Aerial photograph of the pilot area Nessmersiel (East Frisia), source: Google Earth 2008.

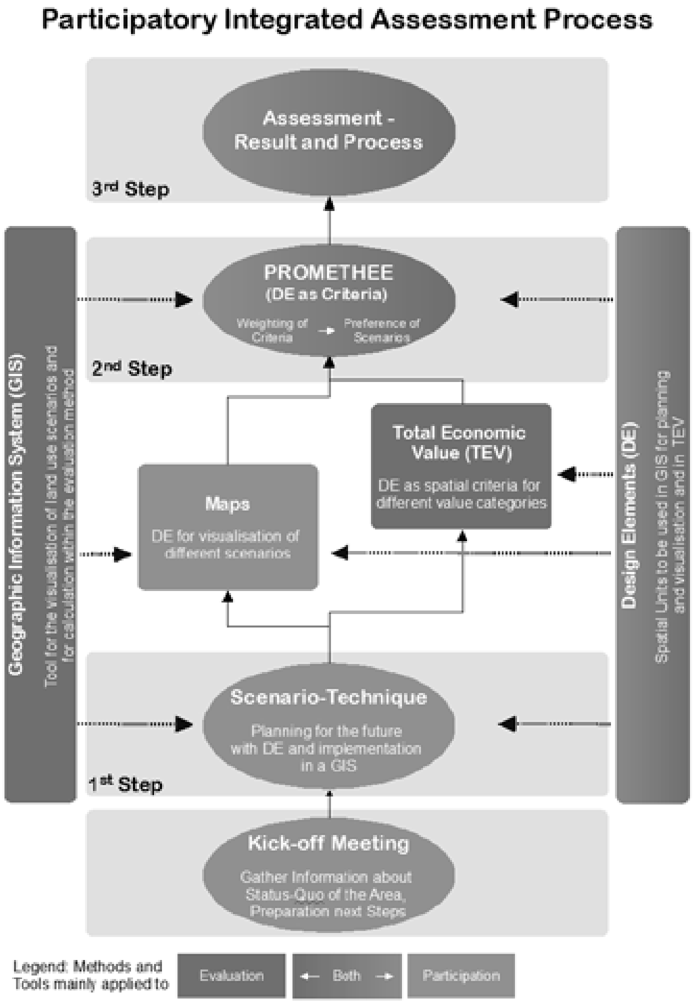

Figure 2: Process diagram for the Participatory Integrated Assessment (PIA) process conducted at Nessmersiel, East Frisia, source: Ahlhorn (2009).

To investigate the feasibility of multifunctional coastal protection zones in Lower Saxony a participation and evaluation process has been conducted with relevant stakeholders in the pilot area, to include coastal protection, nature conservation and agriculture and others. The aim of the participation and evaluation process was to achieve consensus on future coastal zone development (Figure 2). Therefore, basic assumptions about the future development of socio-economic and climatic circumstances have been provided to the stakeholders. These assumptions enclose the upper, the lower and the mean corridor of the future development and have been adapted to the local situation in the pilot area by the stakeholders. Initially, the stakeholders jointly develop land use options for the pilot area according to the basic assumptions. These land use options are the integrated scenarios for the second step. The draft land use options are implemented by a GIS on maps in order to process them within the evaluation method. The evaluation was based on the Total Economic Value approach (Barbier, 1989; Pearce and Turner, 1990) including different value categories such as the use value, the functional value and the existence value (see e.g. WBGU, 2000; Meyerdirks and Ahlhorn, 2007). The applied evaluation method was the outranking method PROMTEHEE (Brans *et al.*, 1984; Brans and Vincke, 1985). Outranking methods are able to handle quantative as well as qualitative data. Two studies have been conducted within the evaluation method, the investigation of reliable data for each criteria and the determination of the weighting. The stakeholders were involved in each of these studies.

The procedure of determining the weights by the introduction of a scoring matrix should stimulate multifunctional thinking across sectoral borders. On the other hand, the procedure should be transparent and traceable. The relevance of the applied spatial criteria should be reflected in the weights calculated at the end of the process.

The result of the process shows that the participatory integrated assessment (PIA) process fulfils these requirements. At the end of the process the stakeholders acknowledged the ability of this process to jointly develop (Are we worrying about split infinitives?) the coastal zone. Furthermore, the implementation of spatial coastal protection concepts offers new options for other types of land use in the coastal zone. For example, if the main dike is to be built as an overtopping resistant embankment, farmers could consider the cultivation of salt resistant or salt adapted crops (this issue will be investigated by the EU Interreg IVB project enerCOAST). On the other hand, the implementation of a defence zone could lead to the breaching of summer dikes and, thus, the restoration of the summer polders to salt marshes, because the coastal protection system consists of a broad foreland, the main dike and the second dike line (Ahlhorn 2009).

5. Conclusions

This brief description of the participation and evaluation process shows that the implementation of multifunctional coastal protection zones is feasible. Within the process all relevant stakeholders of the Wadden Sea Region have been involved, including agriculture, coastal protection, nature conservation, tourism, and spatial planning. The process was transparent and will be transferable to further projects in the coastal zone. The procedure of determining the weighting of the applied spatial criteria stimulates cross-sectoral thinking and achieves multifunctionality (Ahlhorn, 2009). The consideration of different value categories of the Total Economic Value approach (Pearce and Turner, 1990) enables the consideration of the three pillars of sustainable development.

The basic principle of the process and its ingredients was the stimulation of multifunctional thinking across different sectors and the early involvement of all relevant stakeholders. The benefit of, and the support for, solutions will be greater if all parties jointly develop plans and the implementation of spatial criteria is beneficial for more than one type of land use.

Briefly, the benefits of the PIA process can be summarised as follows:

- *Participation* - Relevant stakeholders are involved in each step of the entire process.
- *Vision* - The application of scenarios offers the opportunity to anticipate future development and to adequately create adaptation strategies.
- *Transparency* - The involvement of relevant stakeholders throughout the process leads to maximum transparency.
- *Traceability* - The introduction of the scoring matrix serves as a discussion platform which provides a basis for the consideration and negotiation of spatial criteria and the different land use options.
- *Decision Support* - The application of the outranking method offers opportunities to conduct a comprehensive multi-criteria analysis which takes different value categories into account.
- *Adaptability* - The entire process is built on flexible adaptation to different challenges: new demands in the future and revision under changing circumstances.
- *Sustainability* - The demand for cross-sectoral thinking and the integration of a variety of expert knowledge meets the requirements of sustainable coastal development.

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Mussel culture and subtidal mussel stock management in the western Wadden Sea: are exploitation and conservation compatible?

A.C. Smaal (1,2), J.W.M. Wijsman (1) & M.R. van Stralen(3), aad.smaal@wur.nl
(1) Imares, Yerseke, (2) Aquaculture & Fisheries Dept., Wageningen University, (3) MarinX consultancy

Abstract

Mussel culture in the western Wadden Sea is based on the collection of mussel seed from natural beds, culture of the stocks on bottom culture lots and harvesting consumption-sized mussels. Data from annual assessments of wild and cultured stocks over the period 2004-2008 are combined with collection, harvest and transplantation data to construct annual budgets. An average net gain is estimated to be 3.4 and 19.3 million kg of wild and cultured stocks respectively due to growth and survival which compensate for fishery and harvest. The average total subtidal Wadden Sea mussel stock of about 50 million kg is an important food source for Eider ducks in the area which show a long term maintenance of the winter numbers in contrast to other Dutch coastal waters where a significant decrease occurs. Given mussel stock management by the farmers and the Eider duck numbers it is concluded that Eiderduck conservation and mussel exploitation are compatible in the western Wadden Sea.

1. Introduction

Traditional mussel culture in the western Wadden Sea is an extensive sea-bed culture. Juvenile mussels are transplanted from wild stocks or other resources to culture, or nursery, lots located in subtidal areas in the western Wadden Sea (Figure 1). These are leased by the government to the mussel farmers and at present there are 510 lots in the Wadden Sea with a total surface of 7,700 ha, of which 4,000 ha is in use by the farmers. Not all the culture area is used for growing mussels as the total stock size varies over time and the suitability of lots for growing mussels differs from place to place. As the Wadden Sea is a designated nature conservation area the question arises to what extent the present mussel culture can be combined with the nature management goals of the Wadden Sea: are exploitation and conservation compatible? One of the issues in the debate addresses the role of mussel culture and management of the total mussel stock in view of the availability of prey for protected bird populations such as the Eider duck (Ens *et al.*, 2004, 2006). Therefore in this paper we provide quantitative data on mussel stock dynamics in the Wadden Sea, including the impact of mussel farming.

The mussel stock size on the culture plots is a function of the (i) supply of mussel seed, (ii) growth and survival on the plots, (iii) transplantation to other areas and harvesting for market delivery.

Mussel seed supply is predominantly based on the collection of juvenile and half-grown mussels from subtidal wild stocks in spring and autumn. Annual surveys show that the wild stocks occur in the western Wadden Sea (Marsdiep basin) (Figure 2). Density and distribution of the stocks is quite variable in time and space. Temporal variation is mainly due to annual recruitment success which depends largely on match or mismatch with preda-

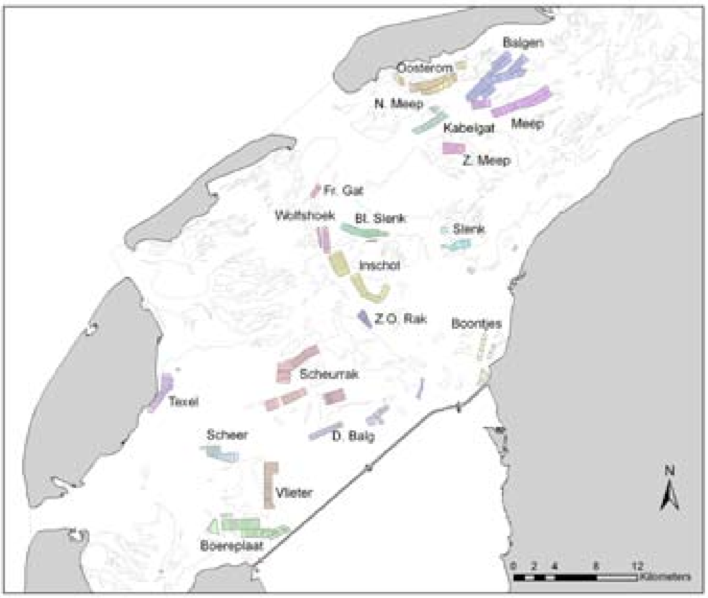


Figure 1: Map of mussel culture plots in the western Wadden Sea.

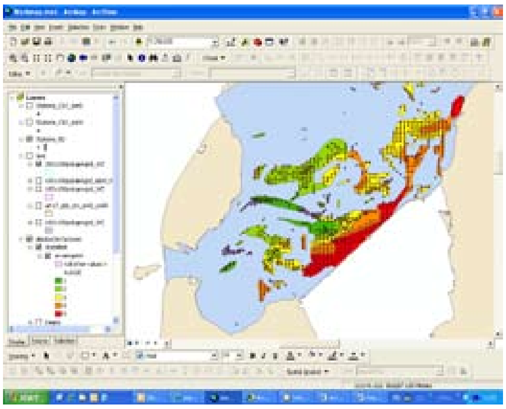


Figure 2: Map of wild mussel stock areas with sampling stations in 2007 and 5 classes of relative stability based on expert judgement: dark(1) and light (2) green = low relative stability; yellow (3) = intermediate; orange (4) and red (5) = relatively high stability.

tors, and with winter temperatures (Beukema & Dekker, 2005). Spatial variation in the survival of wild mussel stocks depends on the vulnerability of areas to factors such as winter storms and predation by starfish. Based on expert judgement and the results of the annual surveys since 1992, wild stock areas are classified in terms of relative stability (Figure 2). It should be noted that, at the moment, intertidal wild mussel stocks are not exploited for mussel seed collection as a result of protection measures.

Growth and survival of mussels in an extensive culture predominantly depends on natural processes. Food availability is a function of primary production, supply by water currents, local mussel densities and occurrence of other filter feeder stocks. Survival depends on the vulnerability of the culture sites to storm damage, and on the occurrence of predators. The farmers manage their stocks by a series of measures which include transplantation of mussels from one site to another, depending on the season and the risk of predation, removal of predators, mixing several stocks and adapting seeding densities to local conditions.

Transplantation of mussels to other areas usually occurs in autumn when a mussel farmer decides to remove part of the Wadden Sea stock to the more sheltered culture lots in the Oosterschelde (SW Netherlands). This includes transplantation of half-grown mussels from Wadden Sea lots in order to provide space for new seed to be brought in, but also a part of the seed might be transplanted directly after collection to the Oosterschelde. It is noticed that natural seed supply is based mainly on collection from the Wadden Sea due to low recruitment success elsewhere. As the Wadden Sea has better growth rates but higher risk of storm damage, it is obvious that transplantation decisions by mussel farmers is part of their stock management strategy to spread risks between the two areas. Existing regulations so far prohibit transplantation of mussels from the Oosterschelde to the Wadden Sea, although this is now subject to revision (Regiegroep mosselconvenant, 2009). The harvesting season is from July till March, and mussels are taken from the plots and transported to the auction in Yerseke (SW Netherlands) as and when the farmer decides (see also Smaal and Lucas, 2000; Smaal, 2002).

In this paper the net effect of mussel culture on the stock dynamics is analyzed on the basis of annual data on seed supply, harvest size and annual assessment data of both wild and cultured stocks. The question of to what extent management by mussel farmer results in a mussel stock in the western Wadden Sea that is not only profitable for economic goals but also for nature management objectives and especially in relation Eider duck numbers is addressed.

2. Materials and methods

2.1 Wild stock surveys

Wild mussel surveys have been carried out in the western Wadden Sea since 1992. Based on experience, surveys are carried out in areas where wild mussel stocks happen to occur. In spring there is a quantitative survey following a grid design with distances of north-south transects of 0.5 or 2 nautical minutes, depending on the expected mussel densities, with distances between the stations of 0.25 nautical minutes. The number of stations varies between 450 and 600 per year. Sampling is carried out with a hydraulic dredge that samples over a distance of 150 m. The dredge has a sampling opening of 20 cm and a mesh size of 5 mm.

Mussels are sorted in three classes on the basis of shell length: seed ≤ 15 mm, seed/half-grown mussels ≤ 45 mm and mussels > 45 mm. Per size class wet weight is determined. In addition, fouling with barnacles and the number of crabs and starfish per station are registered. Data per station are accumulated on the basis of number and weight per sampled surface area, leading to average values per m^2 and total wet weight for all stations.

In August/September the survey is primarily focussed on the detection of new mussel seed. This survey is carried out with a traditional mussel dredge of 1.9 m wide with a mesh size of 8 cm and is considered as a semi-quantitative survey. The survey is done in the western Wadden Sea and sometimes in other areas of the Wadden Sea if there are indications of successful spatfall. About 200 - 300 m is dredged per station and in total 500

– 600 stations are sampled., covering an area of 3,500 – 5,000 ha. Per sample the amount of mussels is estimated and divided into the previously mentioned 3 size classes. Also predator occurrence (crab, starfish) is registered. Gross data are converted to net data by a correction factor which is for seed 0.6 and for larger size classes 0.75.

2.2 Fishery data

Data on the amount of fished mussels is derived from the Dutch Fisheries Board which is responsible for registration of the quantities taken in order to control the fish quota per mussel farmer. Catches are estimated in the field directly after collection. Fishing is based on a fishing plan, for which the survey data are used. The spring survey is 2 months prior to fishery during which period the growth of mussels is considerable. In drawing up the fishing plan, the survey data are therefore corrected for this growth. Gross–net correction is applied as previously mentioned. In this paper only net data are presented.

Fishery data are used for the budget of natural stocks but also as input into the culture stock budget. In addition to fishery, mussel seed is derived from the newly applied mussel seed collectors (MZI). Data on MZI seed input are based on evaluation reports (Kamermans and Smaal, 2009).

2.3 Culture stock surveys

Since 2004 annual surveys have been conducted in autumn on mussel culture lots in the Wadden Sea to quantify the standing stock. On the basis of a pre-assessment by fishery inspectors the survey is focused on the culture lots that are in use at the time by the farmers. On these lots samples are taken following a grid-based sampling design. Sampling stations are located on east-west and north-south transects with a distance of 0.2 geographical minutes, being 223 m and 370 m, respectively. In the four main culture areas, a finer grid was used with a 0.1 minute distance. Depending on the number of culture plots in use a total 400 – 500 stations was sampled. On each sampling station, five Van Veen grab samples are taken and pooled into one sample (total surface 0.276 m^2).

Samples are sieved over 2 mm and mussels are sorted in three classes on the basis of shell length: seed $\leq$ 15 mm, seed/half-grown mussels $\leq$ 45 mm and mussels > 45 mm. Per size class, the mussels are counted and wet weight is determined. In addition, fouling with barnacles and the number of crabs and starfish per station are registered. Data per station are accumulated on the basis of number and weight per sampled surface, leading to average values per m^2 and total wet weight of all stations. By means of a permutation test a power analysis is conducted which shows that given the number of sampled stations the 95 % confidence limits of the average biomass per station deviate less than 16 % from the average values.

2.4 Harvest and transplantation data

The harvested mussels all are traded through the auction in Yerseke that works under the Dutch Fisheries Board. At the auction the total harvest, size, meat content and quality of each mussel is registered and stored in a database. The mussel harvest data are derived from this database. In this paper total harvest data are presented, covering the whole season from July to March.

Transplantation of mussels from growing lots in the Wadden Sea to the Oosterschelde culture plots is not well documented prior to 2007. Therefore, we made the assumption that the harvest from the Oosterschelde is based on half-grown mussels that were transplanted in the year before harvest. We applied a correction factor as the Oosterschelde harvest comes not only from half-grown Wadden Sea mussels but also from the seed fishery in the Delta area, the import of seed from elsewhere (UK, Ireland) and some net biomass increase may also happen. The correction factor was arbitrarily set at 0.75.

3. Results

3.1 Wild stocks

Results from the wild mussel seed survey (Table 1) show a stock size in March that varies from 9 to 36 million kg in 2005 and 2007 respectively. The survey takes place before the seed fishery in the spring season. As shown, the yield varies from 7.5 to 25 million kg, except for 2005 and 2008 when there was no fishing in spring. Table 2 shows the results of the September survey and the subsequent autumn fisheries. Total stocks vary from 5 to 36 million kg, and fishery yield varied from 1.8 to 10.5 million kg.

3.2 Budget of wild stocks

A comparison of total stocks in March and the new spatfall in September minus the amount fished per year gives the net balance between input and output. When this is compared with the actual stock after the autumn season it shows (Table 3) that on average over 5 years there is a net annual gain of 3.4 million kg, which is about 20 % of the annual averaged wild stock size.

Table 1:
Biomass of wild blue mussel stocks from March surveys prior to the spring season fishery, and fishery yields

Wild stock March survey million kg fresh weight					Spring fishery
	≤15mm	15-45mm	>45mm	total stock	million kg
2004	14.7	2.0	6.5	23.3	24.3
2005	0.3	2.3	6.5	9.1	0.0
2006	9.2	1.5	5.5	16.1	7.5
2007	2.8	26.6	6.9	36.2	11.3
2008	3.9	1.5	5.5	10.8	0.0

Table 2:
Biomass of wild blue mussels from September surveys prior to the autumn season fishery, and fishery yields.

Wild stock September survey million kg fresh				Autumn fishery
	≤15mm	>15mm	total stock	million kg
2004	0.9	4.5	5.4	1.8
2005	9.9	12.0	21.9	9.6
2006	0.9	25.1	26.0	3.5
2007	12.0	24.4	36.4	10.5
2008	15.0	3.8	18.8	4.1

3.3 Culture stocks

The culture stock surveys show that total biomass in autumn (end November to December) varied between 15 million kg in 2005 to almost 50 million kg in 2004 (Table 3). This is the stock after the main harvest period, from July to November. Total harvest is also shown in Table 3 and varied from 11 to 30 million kg in 2006 and 2004 respectively. The relatively low harvest in 2006 corresponds with the low stock size in 2005.

3.4 Budget of culture stocks

The balance between input of seed from fisheries and seed collectors versus harvest and transplantation to the Oosterschelde (Table 4 and 5) shows that growth and survival results on average in a net annual gain of almost 20 million kg and this is 60 % of the average annual stock size.

4. Discussion

The budget approach as presented in this paper is a simplification of the processes that play a role in mussel stock dynamics (Bult *et al.*, 2004). Natural stocks are dependent on recruitment, growth and survival i.e. predation, and they are also subject to fishing. It is not clear what contribution different processes make in the dynamics of wild stocks. It can be hypothesized that fishing is detrimental to the development of wild stocks by the removal of part of the stock. However, it is also possible that fishing has positive impacts as thinning out of mussel beds and removal of predators might improve the long term survival of mussel beds and stimulate growth of the remaining mussels. It is likely that fishery impacts are different in areas of different stability (Figure 2). These questions are addressed in a research project where a pair wise comparison is made of areas closed and open to collection (Smaal, 2007). In addition, since spring 2009 a mussel bed of 140 ha in the relatively stable area is closed to harvest in order to allow undisturbed development. This decision is made in the framework of an agreement between the mussel farmers, the NGOs and the government to achieve sustainable mussel culture in combination with nature conservation. (Walker and Van

Table 3:
Budget of wild blue mussel stocks and net result in million kg per year and averaged over 5 year as a function of recruitment (in), growth, survival and fisheries (out).

Wild	Stock T_0 (March)	In	Out	Balance	Stock T_1 (Dec)	Net result
Based on	Spring survey	Autumn seed survey	Spring and autumn fishery	T_0+in-out	Autumn stock - autumn fishery	T_1-(T_0+in-out)
2004	23.3	0.9	26.1	-1.87	3.6	5.47
2005	9.1	9.9	9.6	9.42	12.3	2.92
2006	16.1	0.9	11.0	6.05	22.5	16.48
2007	36.2	12.0	21.8	26.44	25.9	-0.56
2008	10.8	15.0	5.1	20.73	13.7	-7.08
Average	**18.74**	**7.74**	**14.69**	**12.15**	**15.60**	**3.44**

Culture stock million kg fresh weight					Harvest	Transplantation to OS
Year	≤15mm	15-45mm	>45 mm	Total stock	Million kg	Million kg
2004	0.0	16.2	31.8	48.1	30.4	19.3
2005	0.8	8.9	5.2	14.9	26.4	12.5
2006	0.0	6.8	29.0	35.8	10.6	10.8
2007	17.5	3.2	14.5	35.2	26.3	11.3
2008	12.0	2.0	16.0	30.0	21.4	5.6

Table 4: Biomass of mussels on culture plots in Nov/Dec in the western Wadden Sea 2004 – 2008 in 3 size classes, total annual harvest and estimated transplantation to the Oosterschelde (OS).

Culture	Stock T_0	In	Out	Balance	Stock T_1	Net result of growth and survival
	January	From fishery +MZI	Harvest + transplantation	T_0+in-out	December	T_1 - (T_0+ in-out)
2004	30.0	26.1	49.7	6.4	48.1	41.7
2005	48.1	9.6	38.9	18.7	14.9	-3.8
2006	14.9	11.0	21.4	4.5	35.8	31.4
2007	35.8	23.5	37.5	21.8	35.2	13.4
2008	35.2	8.2	27.0	16.4	30.0	13.7
Average	32.8	15.6	34.9	13.5	32.8	19.3

Table 5: udget of mussel stocks on culture plots and net result in million kg per year and averaged over 5 years as a function of seeding (in), growth, survival and harvest/transplantation (out).

Leeuwe, this volume). No results are available for these new developments as yet. Therefore we address the question on the role of mussel culture in stock dynamics on the basis of data that are based on field surveys of culture plots since 2004. The data also allow a comparison with the model approach as presented in Bult *et al.* (2004).

With regard to the dynamics of cultured mussel stocks, the assumption was made that transplantation of half-grown mussels to the Oosterschelde can be based on the harvest in the following year, corrected with a factor of 0.75. Lack of data so far does not allow validation of these assumptions but it can be argued that the mussel harvest from the Oosterschelde is largely based on mussels in more or less similar quantities from the Wadden Sea as net growth and survival in the Oosterschelde result in a production efficiency (yield as a function of stock size) of 1 (Bult *et al.*, 2004) and both local and imported seed supplies are of limited importance. The other elements in the budget, however, are based on quantitative measurements.

The budget for wild stocks in most years shows a net annual increase of the stock per year over the period 2004 - 2008. The low budget value of 2008 is related to high predation by starfish in the autumn of 2007 as shown by the large difference between T_1 of 2007 and T_0 in 2008. Average yield was estimated at about 15 million kg annually which is compensated by spatfall, growth and survival, resulting in a net increase of 3.4 million kg. It is still an open question as to what natural stock size would develop in the absence of a fishery.

For cultured stocks the budget also shows a net annual increase. Total average harvest including transplantation was estimated as 35 million kg per year. Net growth and survival was almost 20 million kg per year. In 2005 there was a negative net result as the T_1 stock (from November/December survey: 14.9 million kg) was quite low. Indeed, the relatively low harvest in 2006 (Table 3) confirms the low stock estimate. However, the budget shows that mussel culture results in a large mussel stock on culture plots that is maintained throughout the years. Total size of wild and cultured stocks was on average almost 50 million kg over the period 2004-2008.

Net budgets of cultured stocks show a higher gain than the wild stocks. This confirms the hypothesis that growth and survival of mussels on culture lots is higher due to cultivation measures than on wild beds, as was the basis of the model of Bult *et al.* (2004). Based on the model it was calculated that mussel culture would result in a higher stock (on average 15 %) in comparison to wild stocks. Data so far indicate that this might be an underestimation.

This stock size represents an important food resource for Eider ducks. Annual bird counts show an overall decrease of the Eider duck population in Dutch coastal waters over the period 1993 – 2008 (Figure 3) (after Arts, 2008). Only the western Wadden Sea is an exception to this long term

Figure 3:
Eider duck numbers showing a significant decrease over time in Dutch coastal waters (Closed circles: total Dutch population, open circles: Wadden Sea population), after Arts (2008).

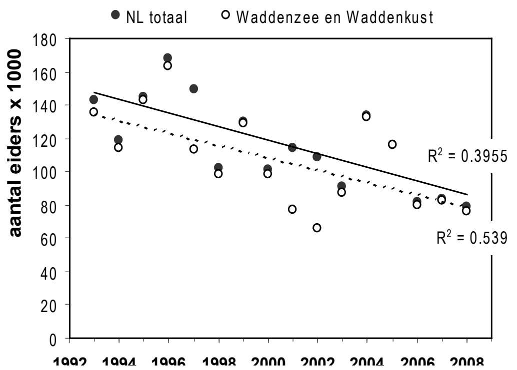
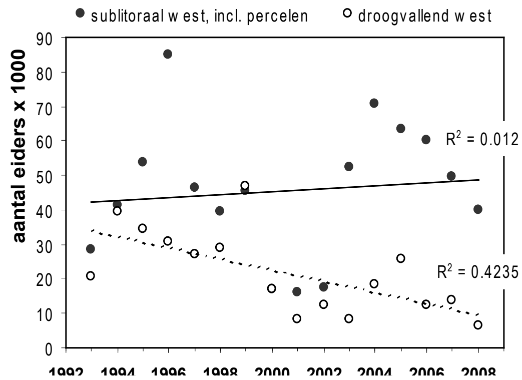


Figure 4:
Eider duck numbers in the western Wadden Sea in littoral areas (open circles) showing a significant decrease, and in sublittoral areas including mussel culture plots (closed circles) with no decrease over the period 1993 – 2008, after Arts (2008).



trend. As shown in Figure 4, despite large fluctuations, the Eider duck population did not show a decrease in the sublittoral areas of the western Wadden Sea in contrast with intertidal areas. It is noted that Eider numbers show a decrease in recent years that does not correspond with mussel stock data. A more thorough statistical analysis including possible factors such as higher winter temperatures, overwintering in the Baltic, role of other food items (Ens *et al.*, 2006) would be required to explain these data. The trends in Figures 3 and 4 indicate the importance of the sublittoral Wadden Sea areas for Eiderduck populations which is probably due to the presence of extensive mussel stocks in the area (Kats, 2007).

It is concluded that mussel stocks in the western part of the Wadden Sea, influenced by mussel cultivation, are maintained at about 50 million kg. Harvest and transplantation to the Oosterschelde are compensated by recruitment, survival and growth including a net gain that is relatively high on culture lots. The available stocks play a role as food for Eiderducks of which numbers in this area have maintained. It is therefore concluded that the exploitation of mussel stocks by man and birds are compatible.

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Do Directives give direction? Integration of nature conservation and fisheries

Paddy Walker & Maria van Leeuwe, Waddenvereniging, Harlingen, The Netherlands,
walker@waddenvereniging.nl

1. Introduction

There are a number of EU Directives aimed at protecting ecosystem integrity. The Wadden Sea is protected by the Birds and Habitats Directives, as well as the Water Framework Directive. In the broader North Sea region the policy decided upon in the Marine Strategy Framework Directive and the (renewed) Common Fisheries Policy will have consequences for the Wadden Sea with regard to water quality and abundance of species such as fish and marine mammals.

The different Directives influence at different levels. The Habitats Directive provides a legal basis for establishing a European network of protected areas – the Natura 2000 sites. Within these areas measures must be taken for the protection of specific vulnerable habitats and species. The Water Framework Directive applies to freshwater and coastal areas and calls for strategies to improve or maintain water quality, aiming for good ecological and good chemical status. The Marine Strategy Framework Directive is a marine equivalent, dealing with the protection of marine waters at the regional level. It calls for strategies to achieve 'good environmental status', including conservation of biodiversity.

Coherence between these Directives is required to ensure long-term protection of the Wadden Sea. The ecosystem approach is generally called upon to supply this coherence. For example, links to, and support of, the Common Fisheries Policy are attempted in the ecosystem approach to fisheries management. However, this is difficult to deliver in practice..

This paper will present a proposal for the application of the ecosystem approach in the Wadden Sea. The agreement of common goals and stakeholder dialogue are the key factors for the success of the integration of human use and nature conservation. The successful application of the ecosystem approach lies in the setting of targets and limits for ecological objectives. The identification of relevant indicators forms an essential link between human use and conservation. A framework for the analysis of cumulative effects will provide insight into the way in which activities can be managed in an integrated manner. The paper will include a case-study linking nature conservation and the management of shellfish fisheries.

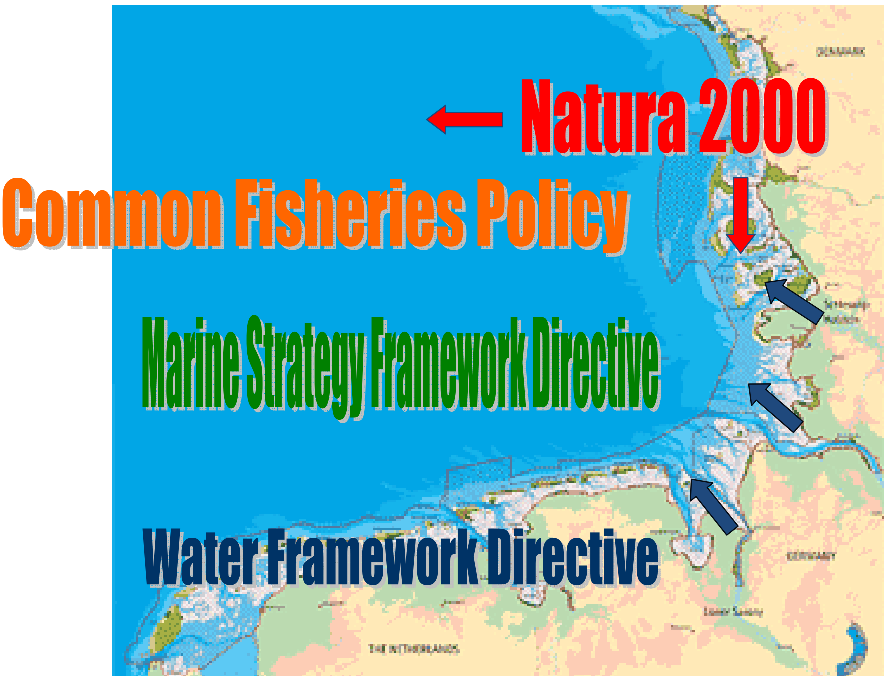

Figure 1: Overview of spatial coverage of the relevant European Directives.

2. Directives and fishing

Directives obviously do give direction for their particular objectives within the specific space and time scale agreed. For example, the objective of the Water Framework Directive is to have Good Ecological Status in each river basin by 2015 (REF). As a result of the Natura 2000 policy there should be a network of closed areas both in the North Sea and the Wadden Sea by 2012 (REFS). For the Marine Strategy Framework Directive the objective is to achieve Good Environmental Status in the North Sea by 2020 (REFS). See Figure 1 for an overview of the different Directives.

However, as far as fisheries in the Dutch Wadden Sea are concerned, the day-to-day reality is that the national licensing regulations are made without taking the broader ecosystem perspective into consideration. To be allowed to fish in Natura 2000 areas, all fisheries have to apply for a licence according to the Nature Conservation Law. These vary according to the fishing activity to be licensed, and moreover are granted by different licensing bodies (see Table 1).

Natura 2000 requires that an assessment of effects in space and time is carried out and that cumulative effects are taken into consideration - the so-called Appropriate Assessment. However, in most cases the scientific knowledge available is insufficient to understand the ecosystem effects of a particular fishery. An analysis of the cumulative effects of different fisheries is virtually impossible due to the high variation in spatial and temporal scales between the different activities as shown in Table 1.

How can the Ecosystem Approach help to provide coherence between the different objectives?

3. The ecosystem approach

3.1 Principles of the ecosystem approach

The ecosystem approach is a concept that has been developed over the past 10 years. It is founded on the principles of ecosystem health and sustainability in which ecological, economic and social objectives are balanced (People, Planet, Profit).

During a Workshop on the Ecosystem Approach held in 1998 in Lilonge, Malawi, twelve principles of the ecosystem approach to biodiversity management were defined. These were presented at the Fourth Meeting of the Conference of the Parties to the Convention on Biological Diversity in Bratislava, Slovakia, also in 1998 (UNEP/CBD/COP/4/Inf.9), and are known as the Malawi Principles. These principles form the basis for most of the (inter)national initiatives for implementation and delivery of the ecosystem approach:

- (1) Management objectives are a matter of societal choice;
- (2) Management should be decentralized to the lowest appropriate level;
- (3) Ecosystem managers should consider the effects of their activities on adjacent ecosystems;
- (4) Recognizing potential gains from management, there is a need to understand the ecosystem in an economic context, considering e.g. mitigating market distortions, aligning incentives to promote sustainable use, and internalizing costs and benefits;
- (5) A key feature of the ecosystem approach includes the conservation of ecosystem structure and functioning;
- (6) Ecosystems must be managed within the limits of their functioning;
- (7) The ecosystem approach should be undertaken at the appropriate scale;
- (8) Recognizing the varying temporal scales and lag effects which characterize ecosystem processes, objectives for ecosystem management should be set for the long term;
- (9) Management must recognize that change is inevitable;
- (10) The ecosystem approach should seek the appropriate balance between conservation and use of biodiversity;
- (11) The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices;
- (12) The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

Table 1: Overview of Dutch fishing activities. .

Activity	Licensing frequency	Licensing body
Mussel – bottom trawling[1]	May and September	Central government
Shrimp	Every 2-5 years	Central government
Cockle – hand raking	Annual	Provincial government
Set nets	Every 5 years	Provincial government
Lugworm dredging	Every 3 years	Provincial government

[1] This is a fishery on the sub-littoral banks. During the year, mussels are removed from the nursery plots in the Wadden Sea. This is not covered in the current licensing regulations

A number of organisations have published guidelines for the implementation of the ecosystem approach. These include FAO, OSPAR/HELCOM, WWF, JNCC and an EEA Working Group EMMA which has written guidance for the implementation of the European Marine Strategy Framework Directive (Cripps *et al.*, 2002; Garcia *et al.*, 2003; EC, 2004; Pope & Symes, 2005; Symes & Pope, 2005).

In short, the ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems.

3.2 Applying the ecosystem approach

WWF has published an overview of Ecosystem-Based Management for Marine Capture Fisheries (EBM) which identifies the essential ingredients for the ecosystem approach (Cripps *et al.*, 2002). The concept of EBM is to achieve sustainability in exploiting natural resources. This embraces both the effect of the environment on the resource being exploited as well as the effect of resource exploitation on the environment. These ideas are developed in detail in a document dealing with policy proposals and operational guidelines (Ward *et al.*, 2002). In this document WWF defines 10 key action points associated with the 9 delivery mechanisms that it is considering for cooperative development with appropriate stakeholders. WWF has defined a number of Guiding Principles:

1. Focus on maintaining the natural **structure** and **function** of ecosystems and their productivity;
2. Incorporate **human use** and values of ecosystems in managing the resource,
3. Recognize that ecosystems are **dynamic** and constantly changing;
4. Natural resources are best **managed** within a management system based on a shared vision and set of objectives developed amongst stakeholders;
5. Management is **adaptive**, based on scientific knowledge, continual learning and embedded monitoring processes.

3.3 Coherence

In order to do the different Directives justice we have to find a common denominator which can take the broader environment into account. Activities in the coastal zone and North Sea directly influence the status of the Wadden Sea – therefore the objectives – and success - of the CFP, Natura 2000, WFD and MSFD are *all* relevant for the management of the Wadden Sea. The ecosystem approach can provide this coherence. On the one hand it states unequivocally that the natural structure and function of ecosystems is the starting point for discussions. On the other, that management is not only science-based, but also based on a shared vision and set of objectives developed amongst stakeholders. These two basic premises provide a framework within which cross-cutting issues can be tackled and solved. See Figure 2 for a schematic approach, following 7 steps.

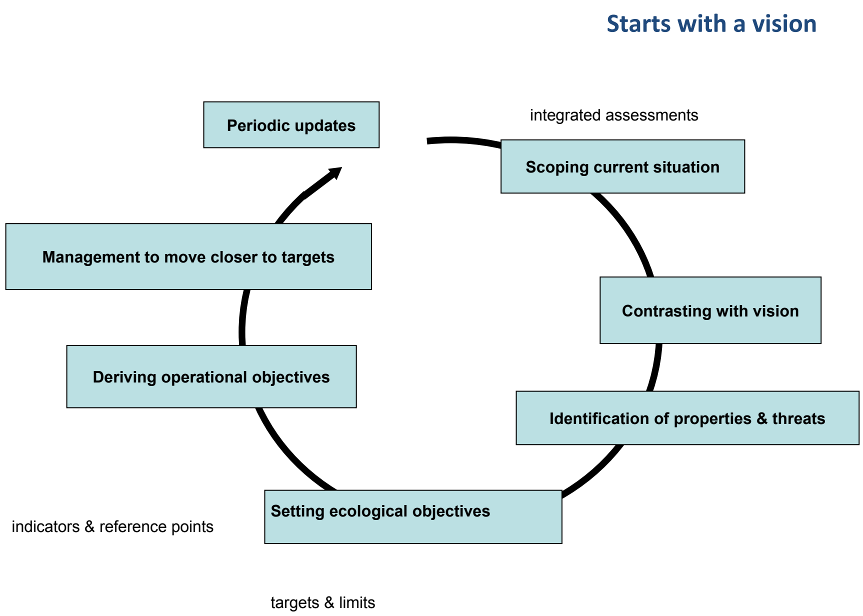

Figure 2: 7-step method for application of the Ecosystem Approach

4. Case study – Dutch mussel fisheries

4.1 Background

In 2005, the nature conservation laws in the Netherlands changed to accommodate the Natura 2000 legislation. According to the new legislation, the fishing industry was obliged to apply for a nature conservation licence, as well as the existing fishing licence. To do this they had to provide an Appropriate Assessment (AA) of their activity, describing the consequences for the designated nature conservation goals in Natura 2000 areas such as the Wadden Sea. In most cases government considered the assessments sufficiently robust to allow fishing. Nature conservation organisations, such as the Wadden Sea Society, thought otherwise. They did not consider the scientific underpinning of the AA to be adequate and were dismayed by the lack of an objective weighing of fishing and conservation objectives. In their opinion it led to continual degradation of the environment. This led to formal objections and several years of court cases in which Dutch nature conservation organisations took the Ministry of Agriculture, Nature Conservation and Food Safety (LNV) to court in order to revoke the Nature Conservation Licence, both for the spring and autumn fisheries.

In 2007, at the same time as the court cases, a confidential process was started with an independent mediator. All the relevant stakeholders were involved – the mussel fishing sector, nature conservation organisations and government – and both the fisheries and nature conservation departments. Issues came to a head when the highest court ruled that the 2006 licence for the spring mussel fisheries could not be scientifically justified and should not have been issued. The verdict came just before the 2008 spring fishing season and led to enormous political and social unrest.

Talks were resumed, eventually resulting in October 2008 in a 'mussel treaty', a Memorandum of Understanding between the parties. Not only was there agreement on how to facilitate the transition of the mussel fisheries, but also on the implementation of an ambitious nature restoration programme in the Wadden Sea. The treaty heralded an unprecedented change in focus and attitude with a move from legal action towards dialogue and consensus on common goals between stakeholders. In the following months the outstanding issues were resolved in a two-tiered approach aimed at creating both scientific and strategic consensus. This is in effect an example of a successful 'Facilitation Strategy' as described by Hanssen *et al.* (2009). This means that societal consensus is sought for a conflict situation, before scientific agreement. The opposite, the Pacification Strategy, in which parties first agree on the scientific underpinning, has been tried in the shellfish debate for a number of years, and has not lead to constructive results.

4.2 Transition of mussel fisheries

The solutions found for the Dutch mussel fisheries are also an example of the first step towards a more integrated and ecosystem-based management of fisheries. Without consciously meaning to, the ecosystem approach has been applied. The basis is the principle that natural resources are best managed within a management system based on a shared vision and set of objectives developed amongst stakeholders. The vision for the transition of the mussel fisheries was based on the following:

- a gradual phasing out of the bottom fisheries;
- the development of alternative mussel seed collection methods, e.g. smart farms.

The ultimate gain is restoration of long-lived and structurally complex sub-littoral mussel banks and a sustainable mussel fishery which is independent of the unpredictable and increasingly poorer spatfall. This is a shared goal both for fishermen and nature conservationists.

Looking at the 7-step approach, we can see that this can also been applied, albeit loosely:

1. Scoping current situation - annual shellfish surveys provide the necessary information;
2. Contrasting with vision - the extent of long-lived and structurally complex mussel banks is small, as is their associated biodiversity;
3. identification of properties and threats - seabed disturbance from mussel fisheries is thought to be partly responsible for low survival of mussel banks and to lead to lower biodiversity; low recruitment of mussels is also a limiting factor – higher water temperatures and changes in predator-prey relationships might be responsible for this;
4. setting ecological objectives - increase the extent of sub-littoral mussel banks,
5. deriving ecological objectives - the indicator will be the area of long-lived and structurally complex sub-littoral mussel banks; reference points have not yet been identified;
6. management to move closer to targets - gradual phasing out of the fisheries; increasing substrate for spatfall (smart farms);
7. periodic updates - annual surveys, monitoring and experiments (see below).

This is summarised in Principle 5 - management is adaptive, based on scientific knowledge, continual learning and embedded in monitoring processes.

A schematic representation of the transition mechanism is shown in Figure 3. Each year 20% of the total area of spatfall as calculated in the spring will be closed for the spring mussel seed fisheries, starting from spring 2009. Mussel seed will be collected via smart farms in the Wadden Sea and Oosterschelde. Once these have reached a production capacity of 5.5 million kg, the next step can be taken – closing 40% of the area for fisheries, and so on. Initially, the autumn fisheries will continue. A number of spot surveys have been planned so that the strategy can be evaluated and adapted if necessary. An extensive monitoring programme is being set up to follow the development of mussel banks, and associated biodiversity, in the closed areas. Experiments are being designed to assess the impact of the smart farms on carrying-capacity and on benthos.

4.3 Nature Restoration Programme

The nature restoration programme is intimately linked with the mussel transition, as part of the MoU and as an ecological objective of the transition away from seabed disturbance. The restoration programme is designed to promote ecosystem management as the general prescription for management in the Wadden Sea.

Nature conservation organisations have committed their vision of the future for the Wadden Sea to paper in "The Bountiful Sea - a vibrant future for the Wadden Sea" (www.waddennatuurlijk.nl). This has been used as a basis for discussions with government for an ambitious Nature Restoration Programme. The Programme is run by a Steering Committee consisting of NGOs and regional and national government. It is a focus for national and international policy and the Implementation Plan is expected to be completed by early October 2009. Five major topics have been distinguished:

1. Restoration of clear water;
2. Enhancing food web dynamics;
3. Large scale restoration of ecosystem engineers;
4. Climate change in the Wadden Sea;
5. Maintaining international context.

The aim is to identify the current status and the relevant threats and pressures. The topics should translate into operational ecosystem objectives, i.e. to restore trophic integrity, for example by the return of apex predators such as skates and rays. Ultimately an integrated suite of management measures will be identified which will lead to the realisation of the 'Bountiful Sea' by 2020. This management will be adaptive and follow a cyclical process. Human use has been incorporated as a cross-cutting topic. For fisheries, a regional group has been set up to formulate a vision for sustainable fisheries in the Wadden Sea.

The approach used has included many of the strong points of the ecosystem approach (science-

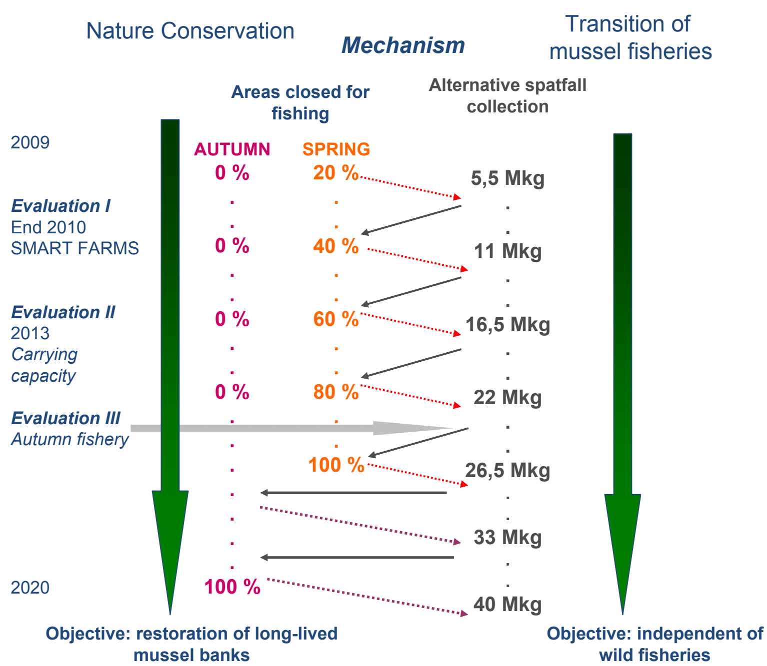

Figure 3: Transition mechanism showing how the sub-littoral bottom mussel fisheries will be phased out. Each step of 20% in the fishing area closed will be 'compensated' by 5.5 million kg mussel seed from alternative sources, starting with smart farms in the Wadden Sea. The phasing out will start with the spring fisheries and move on to the autumn fisheries once 26.5 million kg mussel seed can be won from other sources.

based, integrated approach, stakeholder dialogue) and has the potential to realise the high ambitions it has set. (See Figure 2).

5 Concluding remarks and future perspectives

A good deal of the strength of the ecosystem approach lies in the principle that natural resources are best managed within a management system based on a shared vision and set of objectives developed amongst stakeholders. This has been shown for the mussel fisheries and the nature restoration programme.

The Dutch Wadden Sea Council has already written an advisory note for government on sustainable fishing which contains many elements of the ecosystem approach. This document will form the basis for a regional fisheries group which is currently being set up to develop a vision for fisheries in the Wadden Sea. Once fisheries and fisheries management are organised, either in a stakeholders' group or advisory council or in another form, this will create a forum in which to discuss and implement sustainable use. The discussion can then be taken a step further and address the more complicated issues such as the ambition to reduce the ecological footprint of fisheries, for example to become carbon neutral, or how to facilitate a re-investment in natural resources by fishermen.

The following lessons have been learned from the Dutch situation:

- Work within a relevant policy and management framework – include government!
- Identify common goals;
- Recognise, and respect, differences;
- Plan for the long-term and act on the short-term;
- Cooperation leads to a place at the negotiating table;
- Sometimes an independent mediator is necessary.

The ecosystem approach requires all parties to move away from their traditional comfort zone. Nature conservation organisations are unfamiliar with the negotiating table and are reluctant to compromise on conservation goals. Other parties are afraid of losing their rights. Politics has to take the lead. Implementation of the ecosystem approach and the acceptance of adaptive management do not affect the integrity of the parties involved, but gives a wider focus and allows parties the time and space to arrive at common goals.

There is a tradition of crisis management in the Dutch fisheries. The mussel treaty has given the partners a blueprint for future work. We have a lot of the necessary expertise and commitment to address the issues facing us, but also need to explore how to focus and organise this in order to implement adaptive management and to facilitate the ecosystem approach. This does not mean that science does not have a role to play. It is vital to have the necessary scientific underpinning of the measures taken, but consensus on the route to be followed is more important to drive a way forward.

We recommend exploring the possibilities to arrange for more extensive stakeholder dialogue in order to address the common issues for fisheries in the Wadden Sea.

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The challenge of managing increasing numbers of geese in the Wadden Sea area: the need for objectives and tools to prioritize and evaluate efforts

Jesper Madsen, National Environmental Research Institute, Aarhus University, Frederiksborgvej 399, P.O. Box 358, DK-4000 Roskilde, Denmark, jm@dmu.dk

1. Introduction

The numbers of geese wintering and breeding in Northwest Europe have been increasing dramatically during recent decades. The international Wadden Sea area, including the adjacent inland polder areas, is a major staging and wintering area for several goose species, and conflicts between agricultural interests and farmland feeding geese have increased. Since geese are highly mobile, it has long been recognized that effective management needs a regional (international) approach (Van Roomen and Madsen, 1992). Various management tools and economic incentives have been used to reduce the damage. However, most of the activities appear to be done locally/nationally on an *ad hoc* basis without a thorough prioritization of how to achieve the most cost-effective longer term and regional management while at the same time safeguarding the conservation interests and the recreational values of geese which are regarded as an asset of the Wadden Sea. Furthermore, there has been little coordination between the Wadden Sea countries. Similarly, no overall evaluation of the effectiveness of management has been conducted; hence, specific lessons learned have not been systematically collated and made available for the wider tuning of management.

To move towards a more holistic and international approach to goose management, a trilateral Wadden Sea Goose Management Group has been set up under the auspices of the Wadden Sea Forum. The Group, which consists of representatives from the national administrations, the agricultural sector, nature conservation and science, is charged with preparing recommendations and guidance for the development of a trilateral management plan to accommodate geese in the Wadden Sea region, to be submitted to the 11th trilateral Governmental Wadden Sea Conference in 2010.

In this presentation, the status and recent development of the goose populations concerned are presented. Furthermore, the rationale and basic information and research needs for a strategic management framework are briefly presented. The author of this presentation is part of the trilateral Goose Management Group; however, the viewpoints expressed in the paper do not necessarily represent the collective or official view of the group.

2. Development of goose populations

The Wadden Sea area, including the adjacent polder areas inside the dikes, is used by several populations of geese, mainly on passage and wintering, but also breeding. The five most common populations are listed in Table 1. Their population sizes have increased dramatically during recent decades, and within the last decade, populations have continued to grow, except for the population of dark-bellied brent goose (*Branta b. bernicla*) which has declined since the mid 1990s. Greylag geese (*Anser anser*) breed in increasing densities on Wadden Sea islands and in marshes on the

Population	Breeding / wintering range	Numbers mid 1990s	Numbers 2005-2008	Annual rate of change
Pink-footed goose *Anser brachyrhynchus*	Svalbard DK, NL, B	35,000	60,000	+ 6%
White-fronted goose *Anser albifrons*	N Russia – W Sibiria D, NL, B	800,000	1,150,000	+ 3%
Greylag goose *Anser anser*	Cont. NW Europe Cont. NW Europe, Spain	200,000	>600,000	+ 9%
Dark-bellied brent goose *Branta b. bernicla*	Sibiria DK, D, NL, UK, Fr	300,000	200,000	decrease*
Barnacle goose *Branta leucopsis*	N Russia, Baltic, DK, D, NL NL, D, DK	267,000	700,000	+ 10%

Table 1: The main populations of geese occurring in the Wadden Sea and their population sizes during the last decade. Source: Goose Specialist Group, Wetlands International (Madsen *et al.*, 1999; Ebbinge, 2009), * the population estimate and trend are currently under revision.

mainland, and barnacle geese (*Branta leucopsis*) have started to breed on islands and reservoirs.

It is widely noted that the wintering geese have changed feeding habits. Increasingly they have changed from foraging on salt marshes or extensively farmed grasslands to feeding on intensively managed grasslands and winter cereals (e.g., Van Eerden *et al.*, 1996; Fox *et al.*, 2005; Koffijberg and Günther, 2005). The only exception is the dark-bellied brent goose which has changed its habitat use to feed mainly on salt marshes on Wadden Sea barrier islands as the population has declined.

Furthermore, several species have changed migratory and wintering strategies and site use.

Not only has the population of barnacle geese nearly tripled during the last decade, which has given rise to conflicts with agriculture in the Wadden Sea area, but the duration of staging in spring has been extended by around a month (Koffijberg and Günther, 2005), because geese have increasingly forsaken their traditional spring-staging areas in the Baltic and now stay in the Wadden Sea area until mid to late May (Eichhorn *et al.*, 2009). Greylag geese have increasingly abandoned their wintering grounds in Spain and, probably also favoured by climate change, have increasingly wintered in the Wadden Sea area. Pink-footed geese (*Anser brachyrhynchus*) have, on the other hand, departed increasingly earlier from the wintering grounds in Denmark towards Norwegian spring staging areas, coinciding with the earlier onset of spring (Tombre *et al.*, 2008).

It is difficult to predict the future development of the populations of geese, but it seems realistic that the current positive developments will continue in the near future since populations are likely to be favoured by climate change. Land use in the Wadden Sea area, i.e., within the dikes, is likely to change as well, with more winter crops and bioenergy fuel crops; however, in the near future this is not likely to limit the distribution of goose populations (Wisz *et al.*, 2008). Geese adapt new habits and migratory strategies; it is likely that they will find alternatives. Competition between goose species is likely to become more pronounced, especially with increasing densities of barnacle geese, which may lead to the displacement of other species; however, it will not reduce the overall densities of geese (e.g. Kruckenberg and Kowallik, 2008). Therefore, it is most likely that the conflicts between agriculture and geese in the wider Wadden Sea area are going to remain or even get worse in the near future.

3. Why strategic international management?

The goose populations occurring in the Wadden Sea are migratory and shared between the countries. Management initiatives taken in one region or country are therefore likely to have an effect in adjacent regions. Examples of this are that scaring activities to reduce goose grazing on pastures in northern Norway were probably causing a change in the spring migration strategy of the population of pink-footed goose, leading to an increased pressure on staging areas in mid Norway (Madsen, 2001; Klaassen *et al.*, 2006). Likewise, it is suggested that the decision to stop livestock grazing on salt marshes in parts of the German Wadden Sea to promote natural development of marsh ecosystems has reduced the carrying capacity for geese (Bos *et al.*, 2005), leading to a redistribution of dark-bellied brent geese in the Wadden Sea (Koffijberg and Günther, 2005).

Politically, the three Wadden Sea countries are all members of the EU, hence obliged by the Birds and Habitats Directives to conserve the populations of geese and their habitats; all three countries are also parties to the Ramsar Convention and the African Eurasian Waterbird Agreement (AEWA) under the Bonn Convention and, not least, the Trilateral Wadden Sea Cooperation. This means that there is a strong commitment to act in a concerted way, even though there is scope for a better coordination of actions between the countries.

In that respect, the goose management issue is an interesting case because all three countries 1) experience increasing conflicts between farming interests and geese, 2) share the geese as a recreational resource, both for people who want to observe them and people who want to hunt them (although not in the Wadden Sea itself), 3) see geese as an asset and part of the Wadden Sea ecosystem in themselves. Furthermore, the problems of goose management are shared between countries and the national management authorities will benefit from learning from each other rather than reinventing the wheel.

The countries have, however, different policies and approaches to the management of geese. In The Netherlands, there is a national system including payment for goose damage and 'goose-friendly' farming agreements under the EU agri-environment schemes. In Germany, there is no direct payment for damage, but agreements exist under the EU agro-environment schemes as well as a special Hallig programme. In Denmark, there is neither damage compensation, nor agreements under the agri-environment schemes. Traditionally it has been stated that landowners suffering goose damage to their crops have the possibility to harvest the geese during autumn and thereby get a sort of compensation. This is, however, far from the case in the present situation, where the species causing the most damage are protected.

To illustrate the shortcomings of local management schemes, the recent issue of handling the goose conflict on the island of Mandø in the Danish Wadden Sea is summarised in Table 2. On Mandø, where the polder is used for cattle and sheep grazing, the numbers of barnacle geese have increased dramatically during recent years, with a peak of 20,000 individuals in spring. The island is also a Natura 2000 area, partly designated due to the dense community of breeding meadow birds. Whatever *ad hoc* management option is chosen to resolve the local problem, there will be repercussions for either farming interests, Natura 2000 interests or goose management, because the geese will disperse and, most likely, conflicts will appear in other areas. Therefore, the longer-term sustainable solution is to put the local conflict into a regional perspective.

4. Pre-requisites for strategic trilateral management

The ideal perspective on goose management is a flyway approach, as recommended by the African Eurasian Waterbird Agreement. Taking into account about five populations of migratory geese, which range over more than 15 European countries with highly different political systems and cultures, this will be a long and complicated process. A regional perspective, such as the Wadden Sea, is a suitable compromise, with the advantages outlined above. Going down that route does, however, also limit the options. Thus, it is not the right forum to discuss population control as a possible measure to alleviate the conflict. This is a theme that can be properly discussed and agreed upon only between all the states concerned, i.e. under a flyway agreement. So far, there is no European example of this.

Table 2: Management options discussed for alleviating the conflict between farming and barnacle geese on the island of Mandø in the Danish Wadden Sea.

Management options	Predicted efficiency in terms of goose abundance	Predicted consequences for farming on the island	Predicted costs for management	Demands on management
No action	Goose numbers will increase to carrying capacity, after which they will disperse to other sites	Additional fodder (of lower quality) has to be purchased from mainland; farming on the island is economically at risk	No direct consequences in short term, but possibly negative in longer term	If local farming stops, alternative grazing of meadows has to be supplied to maintain NATURA 2000 objectives
Compensation for damage	Goose numbers will increase to carrying capacity, after which they will disperse to other sites	Additional fodder has to be purchased from mainland; landowners are sceptical due to quality of alternatives	Economic means of compensation have to be installed (agreements on rental or payment of fodder)	No existing mechanisms at hand in Danish wildlife administration; compensation in other areas will be called for
Scaring geese away from the island (including regulation of geese)	Goose numbers will decrease, depending on effort	Cattle grazing can be continued; landowners have to carry costs themselves; approx. one full time person and a vehicle are required during 1 April – 20 May	None	An effective scaring campaign will have undesirable effects on breeding meadow birds, which conflicts with Natura 2000 objectives
Partial scaring of geese	Geese will be scared away from the inner polder, while they are allowed to feed in the outer polder	Landowners must agree on communal grazing regime, starting in the inner polder and later release of cattle in outer polder. Landowners must carry costs themselves; difficult to define. Need for additional fodder	None	Scaring of geese from inner polder will have negative consequences for meadow birds; delayed release in outer polder can reduce cattle trampling of nests; increased goose grazing in outer polder may reduce nest cover opportunities for breeding meadow birds
Introduce hunting on barnacle geese	Hunting may in the long term reduce overall population size, but will realistically have no effect on goose numbers on Mandø within the coming decade	Negligible effect on level of goose damage in the short term; possible longer term positive effects	None	Hunting has to be negotiated and agreed in EU which is a slow process; no backing from National Wildlife Management Council

It is proposed to adopt a strategic approach to coordinated goose management, including:

1. a set of agreed management objectives across the trilateral Wadden Sea;
2. an overall description of the present goose use and prediction of future suitability of the wider Wadden Sea area based on the habitat preferences, spatial interactions and behaviour of the goose species involved; it is important to include both the areas outside the dikes and the polders/mainland areas, because geese use the area as a whole;
3. an analysis of the vulnerability of crops and areas in relation to annual goose distribution;
4. empirical studies of the effectiveness of various management tools as well as prediction of their effects on goose distribution and behaviour;
5. a quantitative prioritization of areas and tools to be used to achieve the most efficient joint management; and
6. a feedback system to collate experience, monitor and evaluate efficiency of the schemes applied, to be used for fine tuning the management.

A recent study performed in Norway, where economic compensation is paid to farmers for accommodating foraging geese on their farmland, has shown how important it is to prioritize management efforts to make them cost-efficient. The prioritization was based on an analysis of site use by geese (they prefer big open fields in the lowlands, close to the coast or bodies of open water), a regional spatial model of the distribution of the geese, and a ranking of all fields according to their value for geese (Jensen *et al.*, 2008). If the authorities will prioritize compensation according to the ranking rather than paying without a priority plan (which is the practice right now), the efficiency, measured in numbers of geese that can be accommodated for a certain amount of compensation available, can be increased more than 10 times.

Such a management support system can potentially be developed for the international Wadden Sea region, but it will require a coordinated research project with the aim to set parameters for a spatial model and select criteria for a priority setting model. In the Wadden Sea area, geese use a variety of habitats in a seasonal sequence, and there are areas where they are welcome and

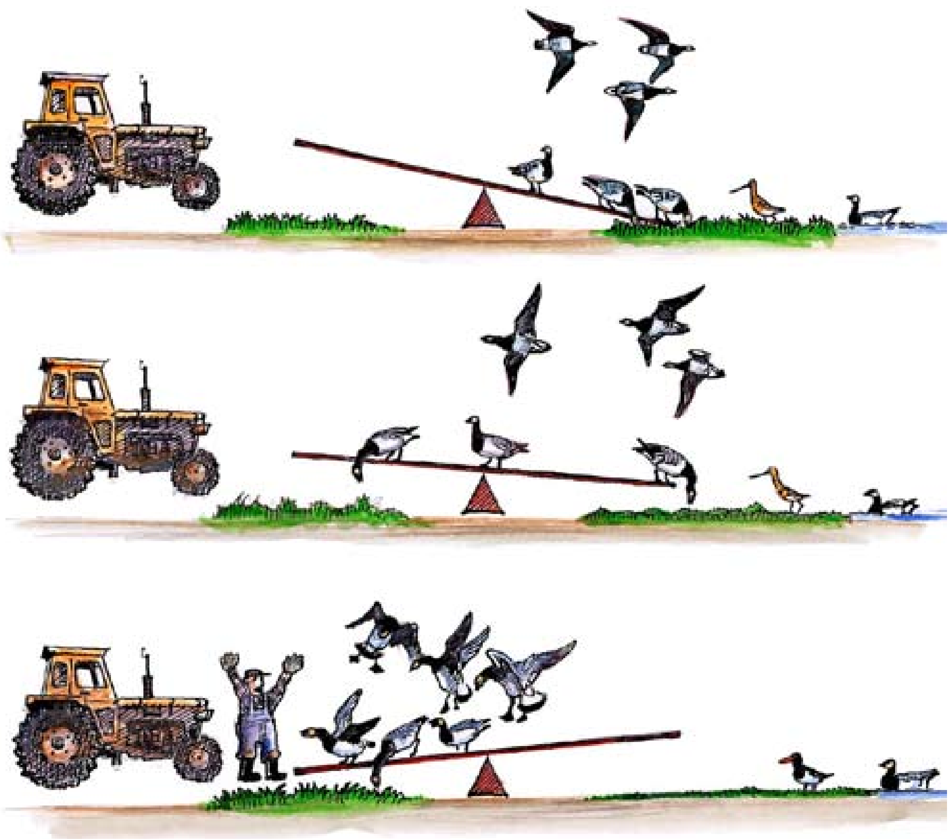

Figure 1: Illustration of the trade-offs geese have to make in choosing between meadows/salt marshes and farmland. As long as food quality and quantity are high in the marshes, geese prefer to stay there; as resources are gradually depleted, food intake rates decline and it becomes profitable to fly over to the farmland. However, scaring by farmers will increase energy expenditure and is perceived as a predation risk which in turn reduces the profitability of the farmland. Quantifying and modelling these trade-offs indicated by the balance will make it possible to predict the effects of management on the distribution of geese. The waders to the right illustrate that intensive goose grazing may potentially affect the meadow bird community "(Drawing by Jens Gregersen).

areas from which they should be deterred ('go' and 'no-go' areas). Hence, there should be a combination of management tools which will improve conditions for geese (improving food quality and quantity; reducing disturbance) and which will deter geese (scaring devices, field planning instruments). How such tools can operate in concert in a mosaic landscape to effectively manipulate goose distribution has to be tested experimentally and their effect predicted by use of modelling. Figure 1 illustrates some of the trade-offs which have to be quantified in such a model. This model should eventually lead to a simple spatial tool (based on a detailed Geographic Information System), which managers can apply for objectively selecting fields for management.

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The Wadden Sea as a cultural landscape and an archive of common history

Hauke Jöns,
Lower Saxony Institute for Historical Coastal Research, Viktoriastraße 26/28,
D-26382 Wilhelmshaven, joens@nihk.de

1. Introduction

There are few areas in Europe where human habitation through the ages has been so dependent on changes in the natural landscape as in the Wadden Sea area. Although both landscape and settlement development are largely determined by sea-level changes, it can be stated that the coastal zone of the North Sea has been occupied and settled whenever it was possible. The economic use of the resources available in the Wadden Sea area, the form and intensity of settling in the regions and, with that, the amount of human and cultural impact to the coastal landscape changed through the ages.

Keeping in mind the definition for a "cultural landscape" given in § 47 of the Operational Guidelines for the Implementation of the World Heritage Convention (UNESCO, 2008), there can be no doubt that, at least parts of the Wadden Sea, for long periods of the past have to be considered as a cultural landscapes. The shape of the past environment was a result of the "combined works of nature and of man". Therefore the remains of lost and inundated settlements are "illustrative of the evolution of human society and settlement over time, under the influence of the physical constraints and/or opportunities presented by their natural environment and of successive social, economic and cultural forces, both external and internal."

For that reason, the recent Wadden Sea as well as its former (today endiked) parts are not only worldwide unique habitats for thousands of species (Gemeinsames Wattenmeersekretariat, 2008), but are also locations where unique remains of thousands of years of settlement and nature history are stored (Vollmer *et al.*, 2001). They form soil-archives that can only be opened with archaeological methods. Based on the information already gained from that archive, the landscape and settlement history can be divided into three phases.

2. First humans in the natural landscape in the North Sea basin (Phase 1)

The settlement along the North Sea started during the Weichselian period, more than 40,000 years ago. Then, the level of the North Sea was more than 100 m lower than today. Most of the recent North Sea basin was dry land and the British islands were directly connected to the continent. Tons of mammal bones and a few artefacts that have been dredged up or washed ashore – most of them being caught in fishing nets – indicate that the North Sea basin was inhabited from that period until the late Mesolithic around 4,500 BC by hunter-gatherer and fisher communities. Due to the melting of the ice masses following the deglaciation, the sea level rose rapidly and continuously and the water submerged the entire North Sea basin (Behre 2007). Although no coastal settlements from the Palaeolithic and only a few from the Mesolithic period have been found, there can be no doubt that the people of these periods were facing radical changes to their environment, forcing them continuously to move their settlements to higher spots and further inland.

The communities of those days exploited the natural resources that were available to them, without influencing or even shaping its constitution. So it could not be said that they were yet living in a cultural landscape. Today, large parts of the area occupied in the late Palaeolithic and Mesolithic period lie submerged in the North Sea or are covered by several metres of sediment (Verhart, 2005). When the deserted settlements were inundated, particularly during high storm tides, their remains were often covered with sediment that preserved them from erosion and in some fortunate cases conserved them for thousands of years until today. The remains of human activities are part of this drowned or covered archive that until now has been only partly opened for research on settlement and environmental history.

3. The Wadden Sea became a cultural landscape (Phase 2)

Around 5,000 BC, the sea level was ca. 4.5 m lower than today and the Wadden Sea had almost reached its current level and size (Behre, 2004). At that time the rate of sea level rise slowed down and phases of transgression and regression started to succeed each other. The Wadden Sea remained a permanently changing landscape. The whole coastal flats were regularly flooded with marine and brackish water, depending on the respective sea level and the tidal range, resulting in continuous transport and deposition of sediment in the flooded area (Behre, 2007). During high storm surges along the sea coast and along the banks of tidal rivers, gullies and creeks, elevated levees consisting of clay or sand were created by natural accumulation. Together with moraine ridges, sand spits and dunes, they offered favourable living conditions for human communities that had developed mixed economies comprising the exploitation of marine and maritime resources, animal husbandry and growing cereals (Louwe Kooijmans, 2006).

The beginning of agriculture in the coastal zone, combined with the establishment of permanent settlements and graveyards, led to clearly detectable changes of the natural environment, so the transformation from a natural to a cultural landscape was under way. The next important step in this direction happened around 500 BC, when people started to build their settlements on higher ground to protect themselves from flooding in periods of rising sea level (Strahl, 2006). With the establishment of thousands of dwelling mounds called terps, wurten, wierden or warften people finally gave a new character to the landscape along the Wadden Sea.

4. The Wadden Sea and the Clay district: different parts of the same Cultural Landscape (Phase 3)

Before today, the most recent phase of the landscape development of the Wadden Sea started around 1000 AD, with dike building along the southern North Sea coast which divided the Wadden Sea into two parts: the tidal flats of the Wadden Sea on the one hand and the clay district on the other. The latter was cut off from inundation and sediment transport and so became permanently available as fertile land for agriculture and habitation (summarising Kühn, 2007). At the same time, new economic activities, such as digging and dredging of salinated peat for the production of salt, were established.

Today dikes, sluices and ditches in the clay district, together with the terps, wurten, wierden and warften are permanently visible elements of the cultural landscape, whereas the remains of inundated settlements outside the dikes in the recent Wadden Sea are often only periodically visible during low tides (Strahl, 2004). Although currents and tidal waters threaten to erode them, they survive as testimonies of the settlement history of the Wadden Sea.

5. Conclusions

In summary, the developments of the recent Wadden Sea and clay district have been greatly influenced by human activities. Both landscapes reflect the process of evolution and have to be considered as relict or fossil landscapes. Whereas the cultural impact in the recent Wadden Sea was highly reduced and almost stopped during the Middle Ages, when dike construction started, the clay district became a completely men-made cultural landscape.

The challenge of long term safeguarding, research and management of the cultural and natural heritage of the Wadden Sea and the clay district must be considered as a common task for the Wadden Sea states and their authorities. Therefore it should be completely integrated into the long-term agenda of the Trilateral Wadden Sea Cooperation.

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Heritage management in the Wadden Sea (in the strict sense)?

Sonja König,
Ostfriesische Landschaft - Archäologischer Dienst, D-29903 Aurich, Germany,
koenig@ostfriesischelandschaft.de

1. Introduction

The term "Wadden Sea" generally refers to an area which is not restricted to the actual tidal flats. As demonstrated by the Lancewad project (Vollmer *et al.*, 2001), the whole coastal region has to be regarded as a distinct settlement area. Nevertheless, the various types of landscape within that area are also very different in terms of conditions for heritage management, technical possibilities and the degree of large-area surveying. In general, one has to distinguish between the Wadden Sea region/clay district and the Wadden Sea in the strict sense of the word.

2. Aims of the national heritage management

- Extensive data in order to assess the occurrence and the condition of monuments (archaeological sites and buildings).
- Preservation of known and unknown sites.
- Protection of monuments against destruction by human influence.
- In the case of destruction due to human or natural factors, documentation and, if possible, recovery and conservation of cultural remains.

3. The cultural heritage of the Wadden Sea and the clay district: state of research

National heritage management depends on information on the existence, location, structure and condition of individual archaeological sites. Without such knowledge, heritage management would not be possible at all. However, the chances of identifying an archaeological site in the Wadden Sea region and in the Wadden Sea itself are far from being equal.

Methods

Surveys: For approximately 100 years, people have been engaged in field walking and collecting artefacts or excavating sites. While this is easy to do on the mainland, things are different on the tidal flats. Here, it is only possible to survey a small area close to the coastline, and this has to be repeated over years. That task is far beyond what national heritage management is able to fulfil; there is neither enough time for field walking nor is this the favourite method of investigation. Nevertheless, there are a number of individuals in the coastal region who frequently walk across the land looking for sites and artefacts. In the clay district, these are professional archaeologists and volunteers (in former times often teachers). In the Wadden Sea, observations are made by volunteers, conservationists and tourists. However, the problem remains that a large part of the tidal flats is not accessible on foot.

Historical Maps: In many cases we know of settlements from written documents, but we do not know their location. There are historical maps for both regions, but the information they offer is very limited. The oldest maps only go back to medieval times and they do not cover the complete Wadden Sea. They do not give us any information about the precise location, the structure, condition, etc. of the cultural remains.

Aerial photography; geoelectrical, geomagnetic, sonar and radar prospection; airborne laser scanning: One has to be a specialist in order to employ these technologies and interpret the data correctly. Furthermore, the complete area needs to be examined – not only once but at regular intervals. Last but not least, these surveys are quite expensive. They offer an excellent opportunity to monitor and manage interventions caused by building projects, but large-scale investigations which are not connected to any building activities are a rare exception.

4. Distribution of archaeological monuments in the Wadden Sea in the strict sense and in the Wadden Sea region

The archaeological sites and especially the historic buildings have been presented in the project LANCEWAD – Landscape and Cultural Heritage in the Wadden Sea Region (Vollmer *et al.*, 2001) in great detail. The maps show numerous archaeological monuments, historic buildings and navigation objects in the Wadden Sea region. But there are no archaeological sites pointed out in the Wadden Sea itself.

In the region of Ostfriesland, national heritage management is divided between one town and three administrative districts. There are 7136 archaeological sites spread over the whole region, and 69 sites in the Wadden Sea. This last number sounds quite encouraging, but there is a difference in quality between the individual Wadden Sea sites: sites in total: 7136; sites in the Wadden Sea: 69 (8 wrecks, 31 settlements, 30 single finds); Wadden Sea sites near the coast/on an island: 19 (1 wreck, 18 settlement sites). Some of these 18 settlement sites could be attributed to the drowned villages of Ostbense, Otzum and Houwingaham. They and many other sites have been discovered by one single volunteer. However, the number of settlement sites should be much higher. We know of many more lost settlements through descriptions of storm tides and the former coastline. There should also be a large number of wrecks. The Wadden Sea presents a special challenge in that it is far more difficult to investigate than the clay district/Wadden Sea region.

Heritage management in the clay district involves working in a comparatively well-known landscape monitoring the consequences of human activity, preserving monuments or documenting them before they are destroyed.

Heritage management in the Wadden Sea means working in a largely unknown area. We do not have sufficient information about the last remnants of a drowned landscape which was once part of the settled coastal marshland. There is no continuous monitoring for archaeological monuments in the Wadden Sea. The discovery of cultural remains depends on currents and shifting soil. The archaeological remains of the Wadden Sea are not only threatened by human interference such as building activities but also natural changes, which can mean both protection and destruction. Future threats also include an increasing building boom in the Wadden Sea, e.g. offshore wind parks. Although it is easier to handle "small" objects like wrecks than entire settlements, it is nevertheless expensive. High-cost equipment (of course not available at every heritage management office), knowledge of maritime conditions, a great deal of long-term research and documentation as well as a discussion regarding the legal situation will be needed.

5. Summary

It is not possible to handle the Wadden Sea area in the same way that other regions are treated by the national heritage management. We do not have enough information about this lost landscape, which once belonged to the settled coastal marshland. There is actually no continuous monitoring for archaeological monuments in the entire Wadden Sea, something which is indispensable for regular heritage management. All technologies which could provide us with urgently needed information are expensive, and it is not clear yet which methods should be used at all. Specialists are needed in order to employ these technologies and interpret the data. The cultural heritage of the Wadden Sea is not only threatened by human impact, especially building activities, but also by natural changes, which may result either in the destruction or conservation of individual sites. Another important factor we have to take into account is a marked increase in construction activities, for example offshore wind parks. Comparatively expensive equipment (of course not for every single heritage management office, but perhaps for one central base in Lower Saxony), knowledge of maritime conditions, much long-term research and recording as well as a debate concerning current legislation are essential.

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Settlement history of a lost landscape – archaeological remains in East Frisian tidal flats

Kai Niederhöfer,
Am Diekpohl 22, D-48268 Greven, kai.niederhoefer@web.de

1. Introduction

The Wadden Sea area of Lower Saxony is widely known as an unique nature reserve, as well as a recreation area and, last but not least, as an economic resource. Less well known is that parts of this area are the remains of the former coastal marsh of the southern North Sea, which was partly populated until the 16th century[1].

This paper concentrates on the East Frisian tidal flats from an archaeological point of view. It is based on the first results of a continuing PhD thesis at the University of Münster and must be considered as a preliminary report. The primary object of this research project is to establish a history of settlement in this lost landscape by interpreting the archaeological material in context with the geological and historical data. The study area comprises the tidal flats and the islands of the major part of the national park "Niedersächsisches Wattenmeer" between the Ems and Jade estuaries, extending to 1700 square kilometres with varying concentrations of archaeological sites.

The development of the sea-level curve with its different phases of transgression and regression over time generates the background for human settlement of the area. This cannot, however, be discussed here in detail. After a long period of continuous sea-level-rise the rate of this trend declines significantly around 7000 to 8000 years ago. From this time, the sea-level-curve shows phases of stagnation, regression and new transgressions[2], which enabled or inhibited settlement activities and which have caused noticeable changes of the coastline over the centuries. Most noticeably, the intrusions of the Dollart and the Jadebusen are still visible today, while others, like the Bay of Sielmönken, the Ley Bay, the Harle Bay, the Crildum Bay and the Maade Bay have been reclaimed by dyking or have silted up naturally (Fig. 1). The discontinuous sea-level rise continues to affect the habitat today.

2. Archaeological evidence for human settlement activities

In this area, archaeological sites have been known since the 18th century. The first notice derives from 1789 when the pastor of the church of Borkum, Dietrich Nicolai, discovered remains of a former settlement in the tidal flats northwest of the Island of Borkum after a storm flood. He mentioned several structures, e. g. footprints of small buildings, wells and cisterns made of divots, which he believed to be the remains of pagan temples and sacrificial altars[3].

Except for a few small, mostly poorly docu-

[1] cf. Niederhöfer 2004.

[2] Last on this topic in the southern North Sea area: Bungenstock/Schäfer 2009; Bungenstock/Weerts 2009.

[3] Nicolai 1811.

Figure 1: Former coastlines in Lower Saxony: around the time of Christ's birth (dotted line), around 800 A.D. (solid line) and around 1500 A.D. (broken line) in relation to today's shoreline (after Behre 2004).

mented and non-systematically conducted studies in the first half of the 20th century, systematic surveys of the East Frisian tidal flats were initiated in the 1980s by Axel Heinze of the Museum "Leben am Meer" in Esens, especially in the coastal area between the communities of Bensersiel and Neuharlingersiel (Joint community of Esens, District of Wittmund). These surveys, which continue today, have increased the number of known archaeological sites in the East Frisian tidal flats enormously[4]. More than 140 archaeological findings from single artefacts to settlement sites have so far come to light across the study area.

3. Single findings from early periods

As a result of the sea-level rise, the shoreline in the southern North Sea area has moved southwards since the Weichselian ice age from the area north of the Dogger Bank to today's shoreline. Archaeological findings in the East Frisian tidal flats and on the East Frisian islands are known since the middle Palaeolithic. The majority of the Palaeolithic and Mesolithic flint artefacts and a few antler tools are single finds, which cannot be dated very accurately.

Artefacts from the Neolithic and the Bronze Age can be more definitely dated: these too are mostly flint and antler tools. It is from this time that the oldest pottery from the study area is known: a sherd of a so-called "bell beaker" from the 3rd millennium BC (Fig. 2).

All these artefacts come from a period with a significantly lower sea-level than today. They originate from the lower Pleistocene and early Holocene landscape, which today lies offshore beneath marine sediments. The artefacts have been disturbed by the tides in the inlets between the islands and subsequently deposited on the beaches of the East Frisian Islands. Therefore, these finds must be considered as secondary findspots. Some of them were found in fishing nets, so their primary findspots are only roughly known. For these reasons it is not possible to locate the camps of the ice age hunter-gatherers and the settlement or burial sites of the Neolithic and Bronze Age farmers in today's tidal flats. The oldest settlement with footprints of wooden buildings known in the clay district of Lower Saxony is Rodenkirchen-Hahnenknooper Mühle in the Wesermarsch district. It dates from the 10th/9th century BC – the late Bronze Age – and was discovered in 1971 nearby a riparian ridge of the Weser far from the shoreline[5]. Comparable remains have not yet been found in the study area.

4. The first settlement sites in the East Frisian tidal flats

The first archaeological sites in the study area which can definitely be identified as settlement sites, usually from their large finds of pottery, are known to date back to the pre-Roman Iron Age.

The focal point for the spread of archaeological sites from this period is in the extensively-surveyed tidal flats between Bensersiel and Neuharlingersiel. Some provided pottery from the early and middle Iron Age (c. 700 – 200 BC) in a rather poor lot. This is remarkable, since the colonization of the coastal marsh has generally not been considered for this period in earlier archaeological research[6].

The oldest radiocarbon date of a settlement site in the study area is of a divot-made hut measuring 4 to 3 metres (Fig. 3) from the middle pre-Roman Iron Age. An oak post was recovered and dated to 340 BC[7]. Larger finds of pottery and an increasing number of settlement sites can be identified from the first two centuries BC, the late pre-Roman Iron Age. By this time the river and coastal marshes of Lower Saxony show a vast colonization[8].

5. Settlement expansion and the first dwelling mounds

The first written sources which refer to the East Frisian tidal flats appear in the Roman Iron Age (c. 0 – 375 AD). At about the time of Christ's birth, the Greek historian Strabo (c. 63 BC – after 23 AD) refers to a populated island in the Ems estuary called "Byrchanis", which had been conquered by

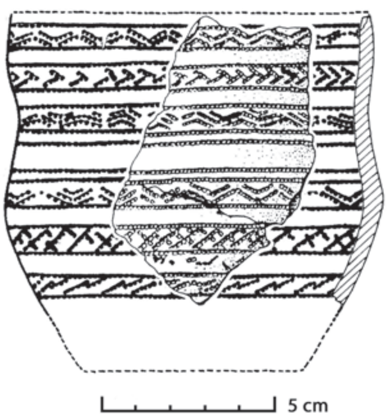

Figure 2: Late Neolithic "bell beaker"sherd from the "Ostfriesisches Gattje" (part of the Ems estuary) and reconstruction of the related ceramic vessel (drawing: Ostfriesische Landschaft, Aurich).

[4] For an overview see: Heinze 1999.

[5] On Rodenkirchen-Hahnenknooper Mühle see in summary: Strahl 2005.

[6] E. g. Strahl 2004, 499-501: Only the river marshes were colonized by this time, e. g. the settlement sites of Jemgum and Hatzum-Boomborg (Community of Jemgum, Disctrict of Leer, Lower Saxony).

[7] Bärenfänger 1997, 2 (footnote 2); Heinze 2003; Niederhöfer 2004, 512.

[8] E. g. Strahl 2004, 501.

Figure 3: Remains of a divot-made hut in the tidal flats of Bense from the second half of the 4th century BC (photo: A. Heinze, Esens).

the Roman commander Drusus (38 – 9 BC)[9] and was possibly later called "Burcana" by the Roman historian Pliny the Elder (c. 23 – 79 AD)[10].

Most of the late pre-Roman Iron Age settlements survived into the early Roman Iron Age. The density of sites in the 1st century AD is even higher. The sea-level rise caused the construction of dwelling mounds, which can still be identified across the whole coastal area of Lower Saxony today. Again Pliny the Elder tells us about the Chaucians, a Germanic tribe living on such dwelling mounds in the Lower Saxonian coastal area. He considered them as very poor people living on their dwelling mounds in the coastal area like shipwrecked people as the tide is coming in[11].

After the 2nd century AD – the middle Roman Iron Age – and predominantly in the second half of the 3rd century and the 4th century – the late Roman Iron Age – the density of archaeological sites declines again probably as a result of the continuing sea-level rise.

[9] Strabo, Geography VII, 1, 3.

[10] Pliny the Elder, Natural History IV, 97.

[11] Pliny the Elder, Natural History XVI, 2-4.

6. The early Saxon cemetery of Ostbense

Findings from the subsequent migration period (375 – 6th century AD), in relation to settlements of the Roman Iron Age are very rare and provided much smaller finds of pottery. Nevertheless, this period provides some of the most spectacular discoveries in the Wadden Sea area. In the tidal flats north of the village of Ostbense, near Bensersiel, two graves from the first half of the 5th century AD have been discovered by chance. The inhumation of a woman contained a bronze elbowed fibula and a silver disc-fibula of "Rhenen" type (Fig. 4). A second grave contained the skeletal remains of a child of no more than three months, buried in an oak vat with a small ceramic vessel as a grave gift (Fig. 5)[12]. Together with some features in worse condition, these two graves are the remains of a migration period Saxon cemetery, like they are also known from other sites in Lower Saxony.

[12] Bärenfänger *et al.* 1997.

Figure 4: Grave of a 40–50 year old woman found in 1993 in the tidal flats north of the village of Ostbense. She was buried in a traditional Saxon costume with two disc-fibulae (diameter: 3.7 cm, only one was found during the excavation) and an elbow fibula (length: 3.5 cm) which are mounted in the top left of the photo (photos: A. Heinze, Esens/ R. Bärenfänger, Ostfriesische Landschaft, Aurich).

Figure 5: Grave of a child buried in a wooden vat. A ceramic vessel (height: 10 cm) was placed beside the vat in the southeast corner of the grave. It is shown in the top left of the photo (photos: R. Bärenfänger, Ostfriesische Landschaft, Aurich).

7. Settlement expansion in the Middle Ages

Since the Middle Ages settlement sites can also be found on the East Frisian islands. Unlike older findspots there, they can be identified as primary archaeological sites at least partly. However, the focal point of the spread remains the area between Bensersiel and Neuharlingersiel.

Few early medieval sites have the typical pottery of the 7th and 8th century, a stone-tempered and mellow baked ware, the so-called "Weiche Grauware". Since the late 8th century the shell-tempered ware – typical of early medieval coastal areas – indicates a further intensive colonization, when a regression phase of the sea-level provided better settlement opportunities.

Figure 6: Bottom slab of a wooden tide gate representing a former dyke built after 1464. Excavated length about 4 m, estimated overall length about 8.8 m, width about 1.6 m Excavated in the tidal flats north of the village of Seriem near Neuharlingersiel in 2003.

Most of these sites show a continuity in their pottery assemblages until high (10th – 12th century) and late medieval times (13th – 15th century). The successional historical tradition in the study area starts in the first half of the 13th century. Since the late 14th century all East Frisian islands apart from Bant and Memmert are mentioned in historical documents. Unfortunately, the settlement sites in the tidal flats between today's shoreline and the islands are almost completely omitted from these records. As a result, our information remains based on the pottery finds and their archaeological context.

The late Middle Ages are also the era of dyking in this area. Since the 13th and 14th century coastal dykes were built parallel to the shorelines. These dykes caused an increasing level of storm tides, because the water was no longer able to spread out over the marsh between the dwelling mounds. The higher levels of storm tides resulted in crevasses with devastating impacts in the late Middle Ages and early modern times.

A noteworthy feature from this period is a tide gate, dendrochronologically dated to after 1464. Its bottom slab has been preserved in the mud and it is the only dateable evidence of an older dyke in today's East Frisian tidal flats. (Fig. 6)[13]. Together with a depression of a former dyke northwards of Bensersiel[14] and a system of ditches, probably a run-off ditch system behind a former dyke[15], it shows the remains of the shoreline stabilisation in this part of the Lower Saxonian coastal area before the All Saints' Day flood of 1570.

8. Conclusions & Perspectives

The All Saints' Day-flood of 1570 marks the chronological limit of this study. This storm flood is one of the most disastrous storm tides recorded in the 16th century, perhaps one of the most disastrous ever in the history of the southern North Sea coastal area. After this, the reclamation of land exceeds the losses. With a few exceptions, which are not reflected by archaeological evidence in the same way as in earlier periods, the era of land loss comes to an end.

Some parts of the East Frisian tidal flats were coastal marsh until the 15th century, and some

[13] Niederhöfer 2008.
[14] Heinze 2002.
[15] Heinze 1989.

until the 16th century. In different conditions, depending on erosion or silting up by the tides, several settlement remains and single finds are preserved by the mud.

This essay tries to give an overview across the breadth of archaeological findings in the East Frisian tidal flats and also to give an insight into the settlement development and continuity of this region, before this once prosperous landscape was finally lost and submerged by the North Sea.

The archaeological remains of the East Frisian tidal flats are part of today's Wadden Sea ecosystem and also an important element in understanding the coastal area, its environment and the way of life beside the sea now and in former times. They must therefore be protected in the same way as the ecosystem.

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Living in a dynamic landscape: prehistoric and proto-historic occupation of the northern-Netherlands coastal area

Annet Nieuwhof,
University of Groningen, Institute of Archaeology, Groningen, The Netherlands, a.nieuwhof@rug.nl

1. Introduction

At first sight, the Wadden Sea area before medieval dike building would not seem to be very attractive to live in from a practical point of view. The salinity of the area and the constant threat of flooding combine to create an environment that could well be considered rather unsuited for permanent habitation. Still, people already came to live there in prehistoric times and what they did there was so successful that the area came to be one of most densely populated in north-western Europe. So, what was it that attracted the first settlers, where did they settle, how did they manage to survive, and to what extent did they influence the landscape? Archaeological research in the coastal area of The Netherlands and Germany has been focusing on these themes for many decades. This paper presents some new insights into the early occupation of the Dutch part of the coastal area.

2. Settling in a dynamic landscape

Circa 5000 years ago, the large tidal basins of the Boorne, the Hunze and the Fivel, former river valleys of the Pleistocene landscape, started to be filled in with sediment. This was a result of the declining relative sea level rise, combined with sufficient sediment supply. As from the Bronze Age, salt marshes were formed that gradually expanded to the north (Vos and Van Kesteren, 2000). The first inhabitants came to the area in the 6th century BC. Occupation expanded to the north, following the growing salt marsh (Vos 1999; Vos and Knol 2005). This continued well into the Early Middle Ages. After medieval dike building, deliberate land reclamation replaced natural silting up; this was only brought to a halt in the 20th century, when the coastline had reached its present form.

There were exceptions to this process of continuing growth. In some areas, massive erosion affected the landscape. At the end of the pre-Roman Iron Age, a large part of the original salt marsh between the present island of Texel and the province of Friesland had disappeared. More to the east, the Middelzee and the Lauwerszee expanded, reaching their largest size in the Middle Ages. Finally, the Dollard came into being in the Late Middle Ages, resulting from a series of erosive events in the Ems estuary.

The salt marsh landscape was a dynamic environment. Not only did the salt marsh grow in some regions and become eroded in others, other factors contributed to its dynamics as well. The salt marshes were flooded regularly; this implied continuing sedimentation of heavy clays where water stagnated, or of more sandy deposits on the salt marsh edges, thus creating relatively high salt marsh ridges or levees (Vos, 1999). Moreover, the youngest, seawards parts of the salt marsh were relatively high compared to the older inland salt marsh, because of the continuing rising sea level. This posed a threat to the drainage of the area. There were also significant fluctuations in salinity, caused by the inflow of fresh water from nearby inland areas, while the rising groundwater level caused the formation of an extensive peat area that separated the Pleistocene inland from the coastal salt marshes. All these factors influenced human occupation of the area.

The attraction of the area to the early colonists must have been the 'nearly unlimited potentialities for grazing', as Van Zeist phrased it (1974, 333). Cattle were of major importance for the occupants of the salt marshes, as was shown from the large byres that were found, for example, in Ezinge (Waterbolk, 1991), the many bones of domestic animals (mainly cattle but also many sheep and/or goats), and the massive layers of dung often found in terps. They were not only a source of food, but also as an important factor in social life (Zimmermann, 1999). The permanent occupation of the salt marsh may have been preceded by a transhumant stage during which cattle were tended on the salt marsh during summer (Van Gijn and Waterbolk, 1984). Supporting evidence for this hypothesis was recently provided by the discovery that, on a number of locations near the city of Groningen, the vegetation had been burned many years in succession, probably from as early as the late Bronze Age and well before permanent occupation started (Exaltus and Kortekaas, 2008). This may indicate that the dry remains of last year's vegetation were burned every spring to improve the quality of the pasture.

The colonists chose the highest parts of the salt marsh for their first settlements, especially the ridges at the seaside edges of the salt marsh. Habitation started there when a new salt marsh ridge was being formed on the seawards side, protecting the new settlement (Vos, 1999). Combined archaeological and geological research over the last two decades has shown that habitation started when the salt marsh ridge had reached the level of a middle marsh (Bazelmans, 2005, for northwestern Friesland; Nieuwhof and Vos, 2008, for northwestern Groningen). A middle marsh is defined as a marsh that is flooded several times a year, not only during winter storm floods, but also during high spring tides in summer. That implies that living on the salt marsh surface, in a Flachsiedlung, was not possible there. It was necessary to raise the living area from the start. During habitation, flooding and sedimentation continued, as can often be observed at the sides of terps (e.g. Nieuwhof and Vos, 2008).

The Flachsiedlung is part of the traditional model of the development of terp settlements. It implies that the first inhabitants settled on the surface of the high salt marsh. In time, flooding made it necessary to raise the living area: the first podia were made. These podia then coalesced, forming terps. Although this model might apply to some terps, it is probable that some of the early remains have not been recognized for what they were: small podia with all kinds of features around them in the salt marsh surface. Archaeobotanical research concentrating on surfaces from the first occupation phase could demonstrate the presence or absence of halophytes in contemporary vegetation and with that, give an indication of the frequency of flooding. However, this type of archaeobotanical research has not been executed as yet during excavations of assumed Flachsiedlungen in The Netherlands.

The early podia were usually made of salt marsh sods. Dung was also used, although there is some regional variety in its use – it is hardly ever encountered in terps in northwestern Friesland. The core of a podium usually consists of arbitrarily placed sods (e.g. in Peins, Bazelmans, 2005), sometimes of layers of clay and dung (e.g. in Leeuwarden, Nicolay, 2008), or exclusively of dung (e.g. in Englum, Nieuwhof, 2008). The podium was consolidated with a broad lining of horizontally placed sods, as could be observed very clearly during the excavation of 2006 in Frisian Anjum (Nicolay, in press). Ditches drained the area around the podia. During habitation, the inhabitants adjusted to continuing flooding and sedimentation by raising and expanding their living area when necessary. Thus, the deepest parts of many terps are hidden by surrounding, younger sediment layers, while only a minor elevation is visible in the modern landscape. In some cases, when the population was too small or sedimentation went too fast, heightening could not keep up with sedimentation, and the terp was left. Such 'frustrated terps' were found, for example, in Paddepoel near the city of Groningen (Van Es, 1970).

A podium was only slightly larger than the house that was built on it. That implies that early settlements not only consisted of one or several houses on their podia, but also of other, so-called off-site structures on the salt marsh surface that did not need the protection of a raised area. A wide area around the settlements was used regularly for all kinds of activities. Ditches and other features such as pits were found, for example near the terp of Hoxwier (Nieuwhof and Prummel, 2007) and under younger layers in Englum (Nieuwhof, 2008).

The use of dung in podia and floors may seem strange, but was in fact a very practical choice. Dung has great insulating qualities and is thus very suitable for layers to live on, in houses and byres (Zimmermann, 1999). Used in surfaces, dung is far less slippery than clay, as many terp excavators can testify (starting with Van Giffen, 1924). Moreover, dung was not necessary for agriculture; yearly flooding of fields enriched the soil with all the necessary minerals. Experiments have shown that manuring of salt marsh fields does not necessarily result in larger yields (Van Zeist *et al.*, 1976).

Manuring brings us to one of the most difficult subjects of terp archaeology: did the landscape allow for arable farming? The brackish soil, the sea wind and the risk of flooding during germination and growing do not count as favourable conditions for growing crops. Experiments on the unprotected salt marsh have shown that it is possible to grow some crops on the sandy clays of the highest parts of the salt marsh, after the spring rains have washed away the salt (Körber-Grohne, 1967; Van Zeist *et al.*, 1976; Bottema *et al.*, 1980). Nevertheless, the experiments showed very clearly that there were many risks involved and that one could never be certain that a usable harvest would result from all the efforts. It is difficult to conceive that people based their existence on such an uncertain outcome. Even though it might be argued that circumstances on the salt marsh were more favourable for arable farming than they are now, owing to the much larger capacity for water storage of the pre-diked salt marsh, a more reliable way of arable farming would seem to be required. Did the early inhabitants of the salt marshes protect their fields in some way?

In 1998 and 1999, excavations were executed in the terps of Dongjum-Heringa and Peins-Oost, in the northwestern part of Friesland. During both excavations, the remains of small dikes were found (Bazelmans *et al.*, 1999; Bazelmans, 2005). Their dating was surprisingly early, compared to the earliest known dikes from the Middle Ages. The dike of Dongjum was dated to the 2nd century AD, while the dike of Peins was even older, dating to the 1st century BC. Of the Dongjum-dike, only a few meters were recovered. However, the dike of Peins could be excavated over a length of 54 m, so that its structure and relation to other features could be studied relatively well. Both dikes were later covered by younger terp layers, while digging activities during habitation had destroyed the top of both dikes.

The dikes had been made in several phases and had a core of salt marsh sods placed criss-cross on the salt marsh surface. These sods were then covered with a further layer of neatly placed sods, thus creating a firm surface that could withstand flooding very well. Vegetation would have continued growing on the sods, thus contributing to the firmness of the covering layer. After the initial phases, the dike of Dongjum was enlarged one more time; the dike of Peins was enlarged at least three more times over a period of several decades, maybe even a century. This period is an estimate, based on the time it would take to form the sediment layers that were found behind the dike on its landward side. After the last phase, the dike of Peins was at least 13 m wide; its height was estimated at about 1.25 m. That implies that its slopes were rather gentle.

Knowing the basic structure, some more dikes could be recognized in older excavations, for example in Wijnaldum (Bazelmans, 2005). The phenomenon may actually not be rare at all. Of course, the first question is: what may have been the function of these dikes?

It could be established that the dikes were made on the middle salt marsh. In Peins, archaeobotanical research of a series of samples from two ditches at the foot of the dike showed that the dike was made on a salt marsh ridge, bordering on a young, low marsh at the seaward side (Nieuwhof, 2006). During the lifetime of the dike, this part of the salt marsh gradually developed into a high marsh. The first podium was made against the slope of the dike when the marsh had developed into a high middle marsh in the first century AD. Then habitation started. This established that the dikes were created long before people actually started to live there. A remarkable feature is the thick layer of sediment behind the dikes. Apparently, the dikes were low enough to allow for occasional flooding; the dikes clearly functioned as sediment traps. Most revealing is that the thick sediment layer was worked and homogenized at some distance behind the dike; the distance would be required to turn a a plough round. In Dongjum, similar evidence was found, though it was not as clear as in Peins due to later disturbances.

It may be concluded that the dikes were probably used to protect arable fields. Such a field would have to be surrounded by a dike at all sides, with a water outlet to drain the area during the summer season. Culverts made of tree trunks from the Roman Iron Age have been found in Vlaardingen in Zuid-Holland (De Ridder, 2005) and near Jemgum on the Ems (Prison, 2009). Its form might have been circular or rectangular; the straight dike fragment of Peins suggests the latter. Such fields would have been protected from most floods, except for high storm surges in winter. Each high flood would have left some sediment that enriched the soil and also heightened the field relatively fast. Archaeobotanical research revealed that grazing did not occur during the earliest stages of the dike; it started later, probably only after the first podium was made and habitation started (Nieuwhof, 2006). The same research showed that the surface directly under the dike did not contain any burned fragments. This was clearly not one of the areas where yearly burning was practiced to improve pasture. We may speculate a little and think of the damage cattle might do to crops (as they did to the crops in some of the above-mentioned experiments). Cattle were clearly not allowed to graze in the vicinity of the fields.

3. Early human influence on the salt marsh landscape

In the above, the early colonization of the salt marsh area was discussed. It was shown that the early inhabitants adapted to this environment in several ways, finding ways to deal with some of its more negative (from a human point of view) characteristics while profiting from others. This section will deal with the influence of human habitation on the natural environment.

There is no evidence that hunting, fishing or collecting shellfish were major occupations of the inhabitants of the prehistoric salt marsh. Among the abundant animal bones in terps, those of wild animals (including birds, fish, and shellfish) are only a small minority. During the pre-Roman and Roman Iron Age, human occupation did not pose a direct threat to animal populations, as was the case from the Late Middle Ages (Prummel and Heinrich, 2005).

A larger impact on the environment may have been made by grazing cattle on the salt marsh vegetation. There were relatively large herds which were probably kept inside at night for safety reasons and to facilitate dung collection. They were herded on the salt marsh in daytime during summer and winter, except during flooding (Nieuwhof and Woldring, 2008). Archaeobotanical evidence (ibid.) shows that in some areas the diversity of the flora did not decrease during habitation, indicating that the area did not suffer from heavy grazing (Schaminée *et al.*, 1998, 99). Elsewhere, heavy grazing probably did cause a decrease of plant species (Woldring and Kleine, 2008). Burning the previous year's plant remains, which may have been practiced in some or many areas, would of course have influenced the vegetation, although it is difficult to assess in what way. It is conceivable that burning resulted in a concentration of nutrients in the soil that would stimulate a more abundant growth of specific plant species. It certainly was not practiced everywhere, as the example of Peins has shown.

Many structures, such as dikes, podia, heightening layers or wells, were made of salt marsh sods. Sods were cut in the environment of the terps. Sod cutting could be studied during excavations in the vicinity of the terp of Hoxwier (Nieuwhof and Prummel, 2007). Within several hundreds of meters from this terp, many shallow, rectangular pits were found in a salt marsh surface from the early Roman Iron Age; these were interpreted as resulting from sod cutting. The pits were usually one spade deep. That means that it was not just the soil that was dug up and used; surface sods were thought to be particularly suitable for such applications. The reason for this is probably the cohesion of surface sods, created by plant roots. In Hoxwier, it was remarkable that even during the excavation, the filling of these pits was still soft and muddy, while thin layers of vegetation remains were sometimes visible in them. This indicates that these pits must have developed into wet, muddy pools that attracted specific plant species (among them reed) in the stagnating fresh water environment of Hoxwier. In a more saline environment, sod pits may have attracted species of the Puccinellio-spergularion salinae, that are well adapted to such circumstances. It may be concluded that sod cutting contributed to diversification of plant species.

There are basically two ways in which the inhabitants of the unprotected salt marsh directly influenced the development of the salt marsh itself, though not always intentionally. The first, as we have seen, was enhancing sedimentation with the aid of low dikes that would allow flooding in winter. This may well have been an intended effect.

The second influence turned out to be quite disastrous in some areas, such as the Middelzee and the Lauwerszee. These former salt marshes areas changed into large tidal basins, due to a combination of natural causes and human activities. One of the natural causes was the increasingly poor drainage of the salt marshes because of the ever higher salt marsh ridges that came to function as barriers for inland water. Especially in Westergo, the Middelzee functioned as a new outlet for the water of the Boorne and other small rivers. However, the effect would probably have been quite limited if human activities had not increased the impact. There are indications, for the Middelzee area as well as for the Lauwerszee area, that exploitation of the seaward margins of the peat area bordering the salt marshes influenced the landscape quite drastically. Draining and peat cutting from as early as the late pre-Roman Iron Age (Waldus *et al.*, 2005; Koopstra, 2002), and salt extraction of sub-surface peat from the early Middle Ages, caused the peat surface to subside, so that these areas came to be affected by the tides. This caused an increase of tidal volume and enlargement of tidal channels, a self-reinforcing process that resulted in erosion of the peat, improvement of drainage and enlargement of the tidal inlet of the Middelzee as well as of the Lauwerszee (Groenendijk and Vos, 2002).

4. Lessons from the past

Changes of the prehistoric and early historic landscape of the Wadden Sea region do not only have historic significance. Human actions in the past influenced the landscape in many ways, for better and worse. Studying this, we may learn something about causes and effects of human activities that we can use when facing modern threats, especially the effects of increasing sea level rise.

In this respect, two insights that were derived from archaeological and geological research may be useful to us. Firstly, people living in the prehistoric salt marsh area did not fight against the sea by building ever-higher dikes, but used flooding seawater to their advantage. They used low dikes that protected arable fields in summer while allowing for flooding and the deposition of fertile sediment in winter. Such an attitude is quite strange to us, modern inhabitants of the coastal areas, who have learned to only trust our dikes. Yet, it may provide us with new and unexpected solutions to environmental problems.

Secondly, draining and cutting peat, and salt extraction from sub-surface peat made the coastal area vulnerable and resulted in great loss of land in the Middelzee and the Lauwerszee areas in the past. We should learn from that to be careful not to repeat this mistake by artificially lowering the land level by, for example, salt mining or the extraction of natural gas. This could well result in an increase of the tidal volume and erosion of the tidal flats of the Wadden Sea, an effect that will even be magnified when the sea level rise increases in line with current predictions. Erosion of the Wadden Sea will pose a serious threat to the dikes and the land behind them, and of course to the Wadden Sea ecosystem as well.

Thus, archaeology not only is a scientific area that provides interesting perspectives on human societies and human survival in the past, it also may provide useful arguments in current debates. Knowledge of the past can be helpful when dealing with the challenges of the present.

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Initiation of dike-construction in the German clay district

Johannes Ey,
Lower Saxony Institute for Historical Coastal Research, Viktoriastraße 26/28,
D-26382 Wilhelmshaven, ey@nihk.de

1. Introduction

Before dikes existed in the North German clay district, the earliest housing settlements in the marshes were found on natural levees. Not later than 2000 years ago, dwelling mounds ('wurten') had been established as residential platforms to protect the population and their property against the North Sea.

Later in this paper, the development of medieval dike construction will be shown, as well as methods of reconstructing the course of those early dikes. As well as looking at early diking in various Frisian landscapes of the clay district, we shall also analyse particular examples of diking in three selected regions of the Lower North Sea marshes: Butjadingen, district of Wesermarsch; Wangerland, district of Friesland, both in Lower Saxony; as well as Eiderstedt, Schleswig-Holstein.

2. Building of the first dikes

Archaeological sources show that the first dikes were embankments of clay sods with gentle seaward slopes. Until the 16th century , carriers and wheelbarrows had clearly been used for transporting the sods from their source seaward of the dike to the embankment under construction. It was not until the 17th century that the 'Wüppe' was introduced. This was a three-wheeled cart pulled by horses and designed to tip. Written records of early diking are very poor. The first to refer to dike construction in the North German clay district are the legal statutes of the Frisian people, 'Siebzehn Küren' (Seventeen Elections) of the late 11th century A.D. (Buma and Ebel, 1963, p. 15). However, in these documents, merely the fact of dike building is mentioned, with no evidence of who was in charge of building the dikes, how they were constructed and maintained, the course or size of those early dikes.

According to historical-geographical investigations (see below), there are three main phases: ring-shaped dikes; low dikes taking their course parallel to the streamlets, and at the seaward end, dikes with their course parallel to the coast. The first and the third phases coincided with the construction of early sluices.

As the ring-shaped dike protects only very small areas, we assume it is the earliest phase of dike construction and we can date its construction to the 11th century. It encircled the infield area of each village community, thereby protecting its arable land against flooding, it crossed no streamlets. Therefore this early phase of dike construction must have been organised and later on maintained by each wurten village community on its own. Recent research reveals that the water table of the winter storm floods during the 11th century was up to about one metre above the mean high water table (Behre, 2003, p. 15). Those early dikes were probably raised above the surrounding area by about one metre and thus the mean high water table by about 1.4m, so presumably protecting settlements and agricultural land even against the high and more dangerous winter storm floods. Therefore, it must have been necessary to install sluices within these ring-shaped dikes, although these have not yet been discovered.

It is extremely difficult to trace and map those early dikes, since they were built so many years ago and in the meantime most of them have been destroyed by ploughing or digging. However, working with historical maps from the 18th and 19th centuries, the course of a ring-shaped dike at the wurten village of Sillens, municipality of Butjadingen, district of Wesermarsch, was reconstructed by analysis of the field-patterns (Krämer, 1984). The dike corresponds to the wurten village of Sillens and encloses an area of about 80 ha. These results of the historical-geographical analysis were later confirmed by two archaeological sections (Schmid, 1988). The medieval dike's height of probably one metre had clearly been ploughed down to about 0.2 m today. The medieval surface remains for about 9 m, which corresponds to the original width of the embankment.

Another ring-shaped dike of a similar age as the Sillens embankment was to the west of Jade Bay within the municipality of Wangerland, district of Friesland. It stretched west of the shoreline of the previous Crildum marine bay and could be traced both by analysis of field-patterns (Nitz and Jachens, 1993, which however gives an outdated state of research) and – for the first time within Lower Saxony – by digital terrain modelling (Ey, 2007). This approach revealed different levels in topography caused by the deposition of sediment inside the ring-shaped dike. Even very low linear remnants of embankments can often be traced by digital terrain modelling. Here, at least two phases of diking can be traced (Fig.1), the older one matching the wurten villages of Oldorf and Neuwarfen and enclosing an area of about 80 ha just like at Sillens. The newer phase encircles an area of more than 300 ha and extends the protected fields by more recently reclaimed marshland in the area bordering the previous Crildum Bay. The width of the embankment's older stage would have been similar to that of the Sillens dike.

About 1 km to the west of Oldorf, the medieval farmers of the wurten village of Pievens had also built a ring-shaped dike. Nearby, and just south of that bay, are some more examples of ring-shaped dikes around the wurten villages of Haddien and Tünnen. Again, two phases of diking can be identified by digital terrain modelling (Fig.1). Only a few km to the south, within the municipality of Wilhelmshaven, medieval ring-shaped dikes were identified by the historical-geographical methods of field system analysis and interpretation of place names (Reinhardt, 2003). Thus, in the western part of the town, the line of a ring-shaped dike matched the wurt of Hessens. Another ring-shaped dike in the eastern part of Wilhelmshaven enclosed the wurt of Heppens. In Schleswig-Holstein, the Danish scholar Saxo Grammaticus refers to low embankments in the marshes around 1200 AD. Archaeological investigations and aerial photos of the peninsula of Eiderstedt revealed, amongst other things, a ring-shaped overflow dike from the 12th century which protected the polder 'St. Johannis Koog' (Meier, 2001, part 2, Fig. 53 et seq.; Meier, 2001, part 1, Tab. 13, 1-2; Fig. 67, stage 6; Meier, 2001, supplement 36.1). In Northern Frisia on the island of Pellworm, the medieval dike 'Schardeich' remained, protecting the polder 'Großer Koog' since around 1200 AD. (Kühn, 1992, p. 31).

3. Construction of low dikes

The second type of embankment, low dikes ('Sietwendungen'), was built from the 12th century and relates to the medieval colonization of the fenlands around Bremen. The technical term 'Sietwendung' corresponds to the Dutch 'Zijtwende' –a term in use from the 11th century – and denotes an early dike orientated rectangularly to the main stream (Renes and van de Ven, 1989, Fig.25). Those dikes had been designed to channel the out-flowing waters from the geest and bog areas, which is why it generally takes its course rectangularly to the later coastal dikes. As the 'Sietwendungen' usually match the parish boundaries, they serve as a watershed between them. Therefore the construction of the 'Sietwendungen' must have been organized and later maintained by one or two parish communities. After the coastal dikes had been built (see below), the 'Sietwendungen' served as wing-dikes which prevented flood waters from entering the area from the neighbouring parish after a breach. Since most of the old 'Sietwendungen' have been ploughed or dug, they can now be traced only by field or path names, or as a boundary between plots of land. Thus in the clay district of 'Land Hadeln', south of the Elbe river, a 'Sietwendung' named 'Langen-Acker' can be traced by field-system analysis; another one is named 'Warnings Acker-Weg' (Ey, 2000, p. 18).

One of very few excellently conserved examples in Lower Saxony is the 'Sietwendung' running parallel to the streamlet of 'Poggenburger Leide' (Fig.1) within the northern part of the previous Crildum marine bay in the Wangerland. It has been well preserved to a length of 160 m, raised above its surroundings by 0.65 m, with a basal width of about 10 m (Ey, 1998). The course of this west-east running 'Sietwendung' is divided into sections by northward and southward turnings of the dike. This leads to the conclusion that from west to east there had been at least four stages in construction of the 'Sietwendung'.

4. Diking of marine bays

As a result of the growing population during the High Medieval Era, it became necessary to enlarge the area available for agriculture. This was achieved mainly by diking marine bays. In the clay district of Wangerland, the Crildum Bay silted up very early, from the Early Medieval period. According to archaeological studies, its western parts seem to have been diked since the late 11th century, which must be contemporaneous with the early – westward – stages in setting up the 'Sietwendung'. Building such dikes which cut off tidal outlets paved the way for the construction of coastal dikes, which – embracing all Frisia – ran parallel to the shoreline and rose above the winter storm tide water table.

According to a postscript in the 'Asegabuch', a Frisian legal statute, such dikes along the North German coast were built from the 13th century (Buma and Ebel, 1963, p. 90 et seq.). However, the documents give no hint of who built the dikes nor what the course and size of these embankments was. As we know by archaeological sections across

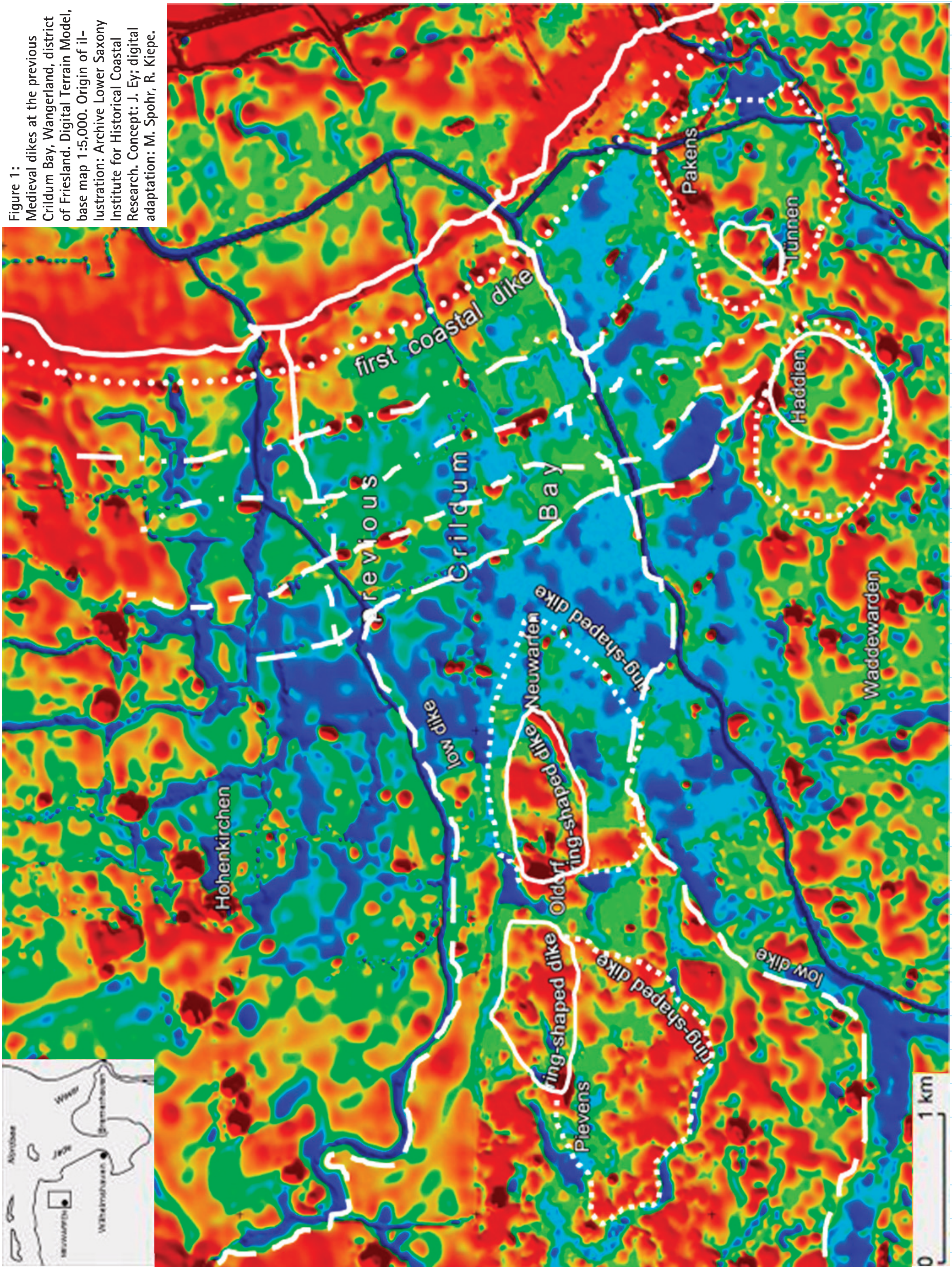

Figure 1: Medieval dikes at the previous Crildum Bay, Wangerland, district of Friesland. Digital Terrain Model, base map 1:5,000. Origin of illustration: Archive Lower Saxony Institute for Historical Coastal Research. Concept: J. Ey; digital adaptation: M. Spohr, R. Kiepe.

some well preserved medieval dikes in the German Federal State of Schleswig-Holstein, these dikes had a gentle seaward slope. This is demonstrated by a dike from the 15th century on the peninsula of Eiderstedt (Meier, 2001, part 1, Tab. 13, 2; Fig. 67, stage 7; Meier, 2001, supplement 36.1).

On the North Frisian mainland, in the 15th century, the first coastal dike was built at the 'Wiedingharde' (Meier, 2001, part 2, p. 119, Fig. 62). South of Eiderstedt, a coastal dike had been built in Dithmarschen from the 13th century (Meier, 2001, part 2, Fig. 69 et seq.). Even in today's tidal flats of North Frisia, remains of medieval dikes close to the 'Hallig Südfall' had already been mapped in the first half of the 20th century (Kühn, 2007, Fig. on p. 268). In the clay district of the Lower Saxon 'Land Hadeln', construction of early coastal dikes is presumed to have started in the early 13th century (Ey, 2000, p. 17). In 'Wesermarsch', remains of a late medieval dike have been investigated. At Stollhammer Ahndeich, a municipality of Butjadingen, the transect through such an embankment revealed an early coastal dike, which was raised above its previous surroundings by about 1.90 m. It is dated earlier than 1362 A.D. (see below; Brandt 1984, pp. 58, 62) and, like the ring-shaped dikes, it must have been equipped with sluices for controlling effluent waters. West of Jade Bay, in the clay district of Wangerland, a coastal dike from the earliest phase, i.e. the 13th century, can be traced both by field-pattern analysis (Nitz and Jachens, 1993) and by digital terrain modelling (Fig. 1; Ey, 2007). Within the municipality of Wilhelmshaven, an early coastal embankment, presumably from the 12th century, has been reconstructed by historical-geographical analysis, connecting the ring-shaped dike systems of Hessens and Heppens (Reinhardt, 2003). It matches the paths of 'Ebkeriege', 'Kopperhörner Reihe' and 'Heppenser Reihe', which later on became roads. In the far northwest of Lower Saxony – the East Frisian clay district of 'Krummhörn' – the bay of Sielmönken must have silted up during medieval times. Historical-geographical examinations have shown that it had been rediked by the 13th century (Reinhardt, 1965).

5. Organisation of dike construction

The Sietwendungen reveal a transition from the locally built ring-shaped dikes to the much more extensive system of coastal dikes which had been constructed from the High Medieval Era in the period of the Frisian Republics of Farmers ('Friesische Landesgemeinden'. While each Sietwendung was probably built by only a few parish communities, the raising of coastal dikes must have been organized on a larger scale by the Frisian Republics themselves, representing all parishes of the region.

Since medieval times, in order to maintain the coastal dikes, the technique of personal, segmental diking was in use. Everybody whose plot was sheltered by the embankment was responsible for a defined section of the dike ('Deichpfand'), the length of which corresponded to the size of the owner's plot. That system applied to routine maintenance as well as to repairs to the dike after storm floods. However, this ran the risk of some owners neglecting their duty, thereby jeopardising the dikes. Therefore, there had to be a change towards communal diking ('Kommuniondeichung'). This did not happen everywhere simultaneously, but continued for several centuries. In the marshes of Land Hadeln, district of Cuxhaven, which previously were part of the Duchy of Sachsen-Lauenburg, it did not happen until the 17th century (Peche, 1931, p. 39 et seq.). There, the parishes in the low-lying marshes ('Sietland') far from the coastal dikes were the first to switch to the new technique. Later on, the parishes of the highly upsilted marshes close to the seaward embankment adopted that system of maintenance. In the marshes westward of the river Weser, district of Wesermarsch, which were previously part of the Duchy of Oldenburg, that change took place from the first half of the 18th century onwards.

Generally, construction of coastal dikes resulted in a severe problem. It blocked the water seaward of the embankment, thereby artificially raising the water table particularly during phases of storm floods. This increased the danger of dike-bursts and, as a consequence, of the marshes behind it being flooded.

6. Sluices

The oldest sluice found in a coastal dike in Lower Saxony was uncovered from the previously-mentioned late medieval embankment at Stollhammer Ahndeich in 1982 (Brandt 1984, Tab. 1). Apparently, the storm flood of Saint Marcel's Day (St. Marcellus) on 16th February 1362 damaged the sluice so badly that it no longer worked. The wooden construction, at least 14 m long, is assumed to have been built before 1362, perhaps around 1300 A.D., but this very rough calculation has to be taken with a pinch of salt. Its seaward section was made of a hollowed oak trunk about 10.5 m long, with an internal width of approx. 0.8 m at its mouth. Its flap lowered automatically at high tide to prevent the rising water from flowing inland. The sluice's landward part consisted of a channel made of oak, which was open with a weir and a slide for regulating the water table in the ditches inland. The internal width of the channel was about 1.5 m and the level fell by 0.8 m from the landward side to seaward.

The captains ('Häuptlinge'), i.e. Frisian rulers of a very small territory, may have organised the construction of the late medieval dikes, and have been responsible for the construction of the contemporaneous sluices too. East of the river Weser, the sluice 'Wehldorfer Schleuse' was found in the 'Alter Hadler Seebandsdeich'. This medieval dike is running parallel to the river Elbe to the east of Cuxhaven. The sluice's tunnel was made from oak, with a square cross section. Dendrochronological dating revealed a date of 1418 A.D. In Schleswig-Holstein an even older wooden sluice from Rungholt, Northern Frisia, has been recorded. It was built no earlier than around 1200 and had two pipes, each with a width of 1.30 m, and a length of 20.50 m (Kühn, 1992, p. 78).

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Landscape and settlement history of the Western Heete Estuary, Butjadingen (district of Wesermarsch, Lower Saxony)

Ingo Eichfeld,
Lower Saxony Institute for Historical Coastal Research, Viktoriastraße 26/28,
D-26382 Wilhelmshaven, eichfeld@nihk.de

1. Introduction

Storm surges, tides and sea level oscillations – coastal areas have always challenged humans to develop suitable strategies to cope with their highly dynamic environment. In order to gain an understanding of this complex relationship, the Lower Saxony Institute for historical Coastal Research (NIhK) builds up a comprehensive and reliable dataset of archaeological site information for the Jade Bay area (Lower Saxony, Germany). This work is carried out within the scope of a multidisciplinary project which aims to develop a web-based data warehouse holding verified scientific and cultural data related to the Jade Bay (cf. preceding article Eichfeld *et al.*).

2. Project area and data sources

The area of the archaeological survey covers the clay region adjoining the Jade Bay and its hinterland, including the administrative districts of Friesland and Wesermarsch, the area of the city of Wilhelmshaven and the communities of Friedeburg, Rastede and Wiefelstede. Information mainly derives from archives, historical maps, literature and other documents of archaeological or historical significance. The primary data source is the sites and monuments database of the Lower Saxony State Service for Cultural Heritage (NLD). This database, called ADABweb, currently holds more than 4100 sites for the area under study. During the first phase of the project, all data was transferred into a desktop GIS (MapInfo) and supplemented by a wide range of digital map data such as topographical, geological or pedological maps as well as digital elevation models and historical maps. In the next phase, which is still ongoing, spatial and non-spatial information is combined and evaluated to determine areas of deficient archaeological knowledge and high potential for further investigation.

3. Archaeology in the Western Heete estuary

One of these areas has been identified around the western estuary of the medieval Heete-intrusion (Fig. 1). The area is located in the southern part of the municipality Butjadingen, a peninsula of the coastal marshland between the Jade Bay in

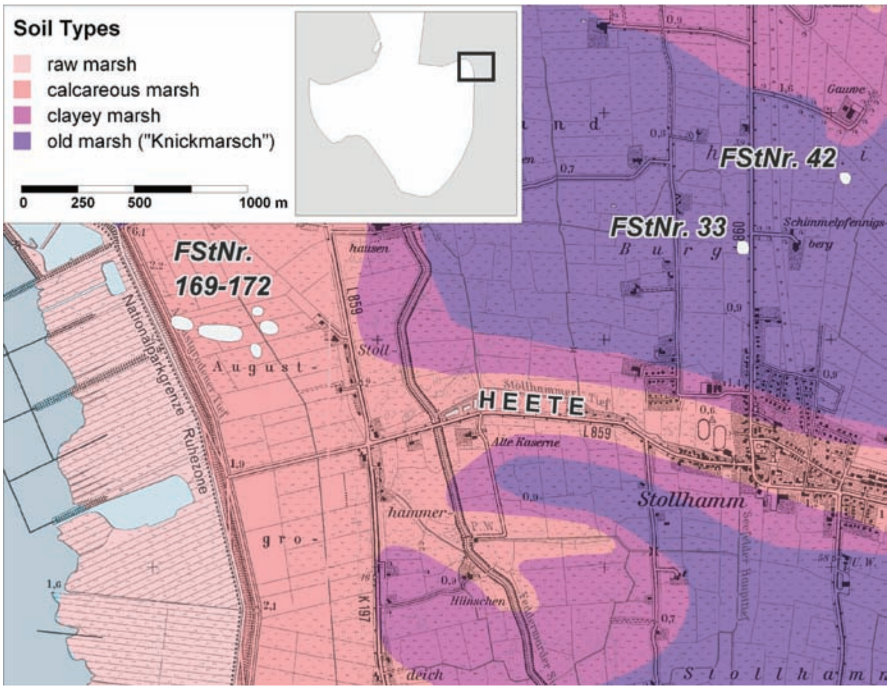

Figure 1: The area of the western Heete estuary: pedological situation and sites mentioned in the text.

the west and the Weser estuary in the east. The area comprises the village of Stollhamm, situated about 2.5 km east of the modern coastline, the hamlet Stollhammerdeich and the adjacent polder called Augustgroden. In contrast to the northern part of Butjadingen, which has been intensively investigated during the 1980s (Schmid, 1991, 29-36), the development of the Stollhamm region is far less tangible. In this area, many sites are buried under extensive layers of younger marine sediments, in particular those of pre-medieval and early medieval times. However, these layers not only impair the chances of discovering archaeological sites, they also improve the preservation conditions of archaeological remains, especially those consisting of organic material.

The earliest sites of the study area known so far have been revealed during small-scale excavations of two dwelling mounds to the north of Stollhamm in 1988. The bottom-most layers of a dwelling mound south to the farmyard Gauwe (FStNr. 42) provided fragments that can be dated to the Late Bronze Age or early Pre-Roman Iron Age. However, it is difficult to ascribe the finds to any occupation layer (Fig. 2). At a neighbouring site (FStNr. 33), about 200 m to the west of the farmyard Schimmelpfennigsberg, the situation is more clear-cut: there, some pottery dating to the older Roman Iron Age has been recorded from the lower-most occupation layer, which also produced wooden remains which were originally part of a wall made of wickerwork (Fig. 2). The occupation layer was superimposed on a foundation of sods, through which the basis of the settlement was slightly raised to a height of about 0.20 m above mean sea level (Ey, 1991). Although the chronology of individual settlement phases cannot be determined, the settlement sequence seems to be interrupted after the initial occupation. The site's further development into a dwelling mound occurred no earlier than the High Middle Ages. Thus, the site belongs to a group of settlements on level ground (Flachsiedlungen), which were established around the Birth of Christ, when a decreasing sea-level made a colonisation of the salt marsh possible (Behre, 2004, 44-49). Like many other settlements it was abandoned when sea-level rose again, while other sites (e.g. in the north of Butjadingen; cf. Schmid, 1991) were raised to dwelling mounds. However, the site is remarkable because it is located well inland, within the low-lying hinterland, while most settlements on level ground have been uncovered on coastal or riverside levees (Behre 2004, 45).

Until today, no sites dating to the younger Roman Iron Age or early Migration Period have been identified in the Stollhamm area. Later on, in the sixth and seventh century, the region seems to have been affected by the apparent decline in settlement activity that has been observed in almost all regions of Northern Germany. Butjadingen was settled again in the seventh or eighth century

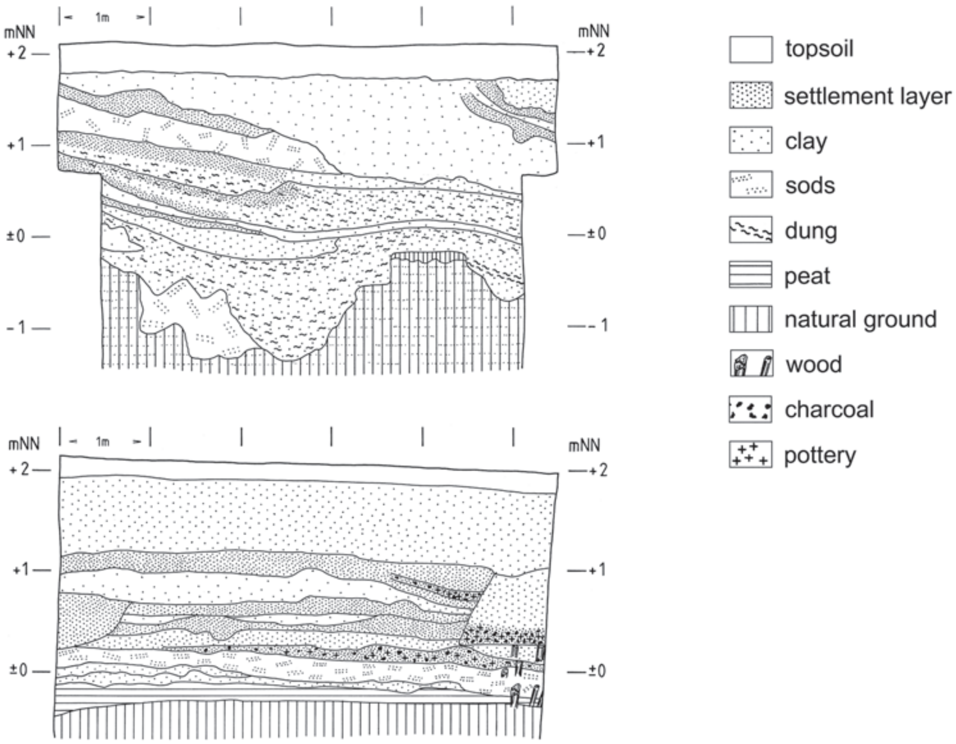

Figure 2: Profile through the dwelling mound FStNr. 42 south to the farmyard Gauwe (top) and FStNr. 33 west to the farmyard Schimmelpfennigsberg (bottom).

(Behre, 2004, 47 p.). It is at about this time that the first written accounts appear. The documentary evidence is of particular importance since it directly contributes to the palaeogeography of the study area. It proves that Butjadingen originally belonged to the Frisian province of Rüstringen ("pagus Hriustri"), which was one of the historic Frisian districts where Willehad, the Bishop of Bremen, was assigned in 787 to do his missionary work. In 826, the "comitatus Riustri" is mentioned as a present from emperor Ludwig the Pious to the Danes' king Hariold. Further sources, like the so-called "vita Willehadi" from about 860, report on the borders of the old county (Finckenstein, 1975, 12-25; Sello 1928, 326-360). Interestingly, none of these early sources provides clear indications for a broad gap in the shoreline such as we see it in the Jade Bay nowadays. On the contrary: the political and ecclesiastical organisation suggests that the area was undivided. That means that the Jade Bay did not exist at that early date. In fact, even at the beginning of the 13th century the region appears undivided. First evidence for a division is found in a document of 1314, which refers to a region called "Bovenjadingen" (Finckenstein 1975, 19). From this a complementary "Butjadingen" can be inferred. Shortly after that, about 1350, the name "Butjadingen" ("Boit-Jatha") is mentioned for the first time (Sello 1928, 355).

Nowadays it is generally supposed that catastrophic floods at the beginning of the 13th century initiated the formation of the Jade Bay and thus led to the division of the region into two independent political entities: "Bovenjadingen" and "Butjadingen". The name Butjadingen derives from the Low German word "buten" and the name of the river Jade. "Buten" means "outside", hence the name "Butjadingen" can be interpreted as "the land on the other side of the Jade river".

This onomastic information is supported by geological drillings. They revealed a Pleistocene channel system, aligned northwest to southeast, through which the medieval storm surges made their way into the hinterland (Sindowski, 1972). Bigger land losses were probably initiated by the first St. Marcellus flood in 1219 and the St. Lucia's flood in 1287 (Behre, 1999, 19-26; Reinhardt, 1979, 40). Further storm surges in the 14th century brought severe devastations all along the North Sea coast. Territorial changes were surely caused by the St. Clemens flood in 1334 and, in 1362, by the second St. Marcellus flood, which is also known under the name "Grote Mandränke", literally meaning the "Great Drowning of Men".

In Butjadingen the floods created a link between the Jade Bay and the Weser river. Thus, for a time, Butjadingen became an island. The water was called "Heete", which means kolk or pothole created by the rapidly rushing water when the dyke collapses (Woebcken, 1934, 26). The course of the marine intrusion can be pursued on the basis of place names and landscape characteristics. A hollow south of the village of Atens, for example, is still known as "Heete" and a road to the north of it is called "Heetweg" (Tenge 1912, 8). Furthermore, the intrusion is reflected on pedological maps, since the former Heete channel is filled with younger marine sediments rich in calcium carbonate, while the adjacent areas are formed by the so-called "Knickmarsch", which is an older decalcified soil with a dense clayey layer (Fig. 1). Last but not least, the channel is clearly visible in geological sections published by the State Authority for Mining, Energy and Geology of Lower Saxony (Müller, 1961; Voigt, 1972).

Though we know that the intrusion of the Heete occurred in the course of the 14th century, there are only a few, partly contradictory sources to pinpoint the timing of this event. Brandt (1984, 61) convincingly associates the incident with the catastrophic storm tide of 1362, but it is not until 1400/1401 that the Heete is mentioned as a border water between Butjadingen and the adjoining Stadland (Brandt, 1984, 62). At that time, the Heete river seemed to have been an open watercourse of at least 186 m width, as Sello (1928, 358) has calculated on the basis of an historical account of a ship bridge that was built by troops from Bremen. However, a hundred years later the Heete must have been embanked again, because otherwise it would not have been possible to establish the village of Stollhamm, which is located within the former channel and mentioned in 1500/1501 for the first time (Finckenstein 1975, 24).

The discovery of a lost settlement located about 2.5 km to the west of the village of Stollhamm provides an insight into the extent the settlement landscape was altered by the Heete intrusion. After the site (FStNr. 169-172) was accidentally uncovered by dike constructions in 1999, a rescue excavation was carried out under the direction of J. Eckert (2004), Lower Saxony State Service for Cultural Heritage (NLD). The investigation implied the documentation of a trench of about 150 m running right through the dwelling mound. Another trench revealed a church mound which obviously belonged to the settlement. In addition to the rescue excavation, archaeological drillings were performed by B. Petzelberger (NIhK). Excavations and drillings resulted in the following model: in the ninth century several small dwelling mounds were piled up from clay, sods and dung. Later on, by filling the gaps between the core mounds, a large linear dwelling mound developed. Furthermore, the construction of smaller dwelling mounds to the east of the major settlement suggests that the place grew quickly. The 12th or 13th century saw the building of a church mound. Foundation trenches with layers of clay and bricks presumably belonged to a stone brick church of about 12 m width and 22 to 28 m length. To the south of the church, five burials were encountered, each of which was covered with a large board. The first damage from storm surges seem to have occurred in the 13th century. However, the final destruction was a result of a heavy storm surge in the late 14th century. The water cut off the upper part of the dwelling mound and covered the site with marine sediments. After that, the area was more or less untouched and open to intertidal accretion until its embankment and reclamation in 1854. The coastal sediments covering the site and the use of dung for the rise of the dwelling mounds offer excellent preservation conditions, in particular for organic materials. This is why the site has been excluded from a designated clay extraction area and conserved for further investigations.

4. Archival surprises

The planning of archaeological drillings now led to a detailed revision of old field journals and other archival material related to the area. These inquiries revealed that the site had already been subject to archaeological investigations by Heinrich Schütte in the 1920s and Werner Haarnagel at some date previous to 1964. Schütte (1925) observed two little "bumps" and carried out archaeological drillings which proved the elevations to be dwellings mounds. He supposed the sites to be remnants of the lost hamlet of "Wiske" whose inhabitants guaranteed – according to written sources – safe conduct for the merchants from Osnabrück to the near-by market at Aldessen in 1318 (Oldenburger Urkundenbuch II 278). A memorandum summarising the results of Werner Haarnagel further emphasises the archaeological significance of the site. Drillings by Haarnagel not only demonstrated a four-phase sequence for the dwelling mounds to the east of the main site, they also argued for the existence of a settlement on level ground at the base of site FStNr. 171. If this can be confirmed by future drillings and the dating of the site can be determined, it will be interesting to relate this settlement to contemporaneous sites in the area, particularly to the nearby settlement on level ground located west to Schimmelpfennigsberg. Furthermore, the example of Stollhamm shows the importance and the potentials of the ongoing project.

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The Jade Bay Project – a summary of targets and planned activities

Ingo Eichfeld (corresponding author, eichfeld@nihk.de), Alexander Bartholomä, Melanie Beck, Friederike Bungenstock, Holger Freund, Martina Karle, Ingrid Kröncke, Ulrike Schückel, Annette Siegmüller, Alexandra Silinski, Viola Stratmann, Achim Wehrmann, Wolfram Wartenberg

1. Introduction

In a multi-disciplinary project, financed by the Ministry for Science and Culture of Lower Saxony (sponsorship programme: "Niedersächsisches Vorab der Volkswagen Stiftung"), one federal authority and four research institutes collect and evaluate cultural as well as scientific data for the Jade Bay area (Fig. 1). The purpose of the project is to provide a web-based data warehouse holding comprehensive information about the development of the marine-terrestrial environment since the end of the last cold stage. Existing and newly collected data are related to each other and examined with regard to their natural and human determinants. The resulting database will be an important vantage point for further research, coastal management strategies and the assessment of future changes triggered by global warming and the industrial expansion of the area, for example by the construction and operation of the Jade-Weser-Port.

Project partners are the Institute for Chemistry and Biology of the Marine Environment (ICBM), University of Oldenburg, the National Park Administration Wadden Sea Lower Saxony, the department of Marine Science of the Senckenberg Institute, the Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN) as well as the Lower Saxony Institute for Historical Coastal Research (NIhK). The following article highlights objectives, methods and planned activities of the different sub-projects within the Jade Bay project.

2. The geological and palaeo-environmental setting of the Jade Bay

The overall sedimentary record along the German North Sea coast may be characterised by Pleistocene glacial deposits disconformably overlain by a Holocene sediment body. Its sedimentary record is wedge-like in shape, thickens from shoreline towards barrier islands (approximately 25 m) and images repeated peat formation, flooding and marine transgression over time. However, within the Jade Bay, hardly any data exist that document the Holocene transgression-regression cycles. The detailed geological setting, along with drainage pattern and geomorphological information remains unclear.

Figure 1: Location of the project area in the Wadden Sea Region.

2.1 Offshore core drilling

Focussing on the genesis of the Jade Bay with respect to former marine, terrestrial and cultural influence, geological interpretation will be drawn from core drillings using vibrocore and pneumatic dynamic probing techniques, carried out by the ICBM. In order to emphasise the three dimensional spatial distribution of the Holocene sedimentological catchment area, data gained will be correlated with the hydroacoustic record (see chapter 2.2 for details). The resulting model for the inner Jade Bay area will then be adapted to facies analysis taken from drill cores within ancient land-sea transition zones (see chapter 2.3 for details), leading to a better understanding of the Jade Bay palaeoenvironment.

2.2 Modelling Holocene sediment architecture using hydro-acoustics

Hydroacoustic surveys including seabed classification with a single-beam sonar and shallow water reflection seismics are arranged along a NE-SW-transect (Senckenberg Institute; Fig. 2) and some deeper channels in the Jade Bay. The seabed classification enables the lateral resolution of the seafloor whereas high frequency reflection seismics offer the possibility of gaining a vertical resolution of the uppermost sub-bottom section. The shallow water seismics are carried out with a boomer system and a parametric sediment echo sounder. Boomer seismic measurements were already done in the main channels during spring time 2009. Based on the new seismic reflection data, additional well positions are scheduled along the transects (cf. chapter 2.1). Seismic records and stratigraphic data of the wells will be linked in a 3-D reconstruction model to locate the Holocene base and reconstruct the entire Holocene sequence. Furthermore, seabed classification data will be used for mapping the recent lateral sediment distribution in the Jade Bay.

2.3 Land-sea transition zone and salt marshes

This part of the project, also performed by the Senckenberg Institute, deals with the change of the coastal landscape during the Holocene sea level rise, focussing on former salt marsh belts, silting-up zones and inward cutting tributaries. By sedimentological and palaeoecological investigations into sediment cores, the position, structure and extension of these structural features at the land-sea interface can be reconstructed, giving an idea of the processes and reactions taking place during sea level changes. As vegetation and diatom associations indicate a high resolution position in relation to the level of mean high water (Watermann *et al.* 2004), a facies analysis may lead to a reconstruction of different mean high water levels and their respective coastlines in the past 10,000 years. The main focus of study is on the region of a flooded area during medieval storm

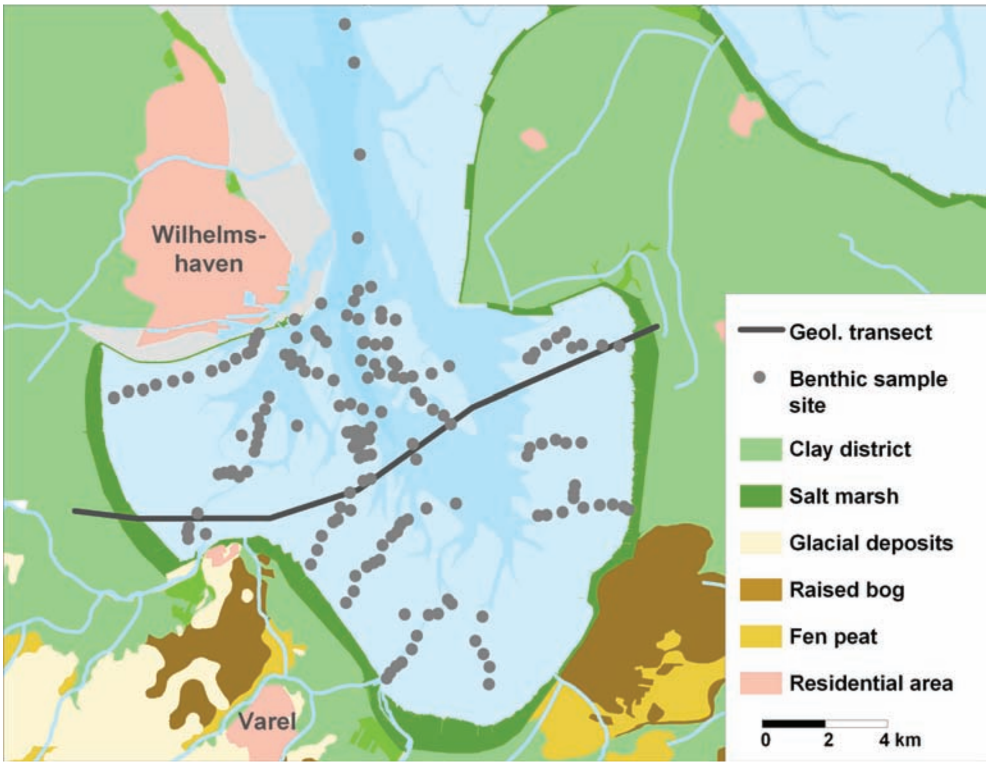

Figure 2: Schematic overview of the project area.

tides, the so called "Schwarzes Brack", southwest of Wilhelmshaven. Furthermore, existing data from the State Authority for Mining, Energy and Geology of Lower Saxony (LBEG, Hannover) will be used and interpreted with regard to climate indicators in order to reconstruct the evolution of the coastal region (Streif, 2004).

3. Human activities and environmental change

Past human communities not only reacted to environmental changes, they also altered the landscape according to their cultural needs and possibilities. As a consequence, the project draws special attention to evidence illustrating the changing roles humans played in landscape development.

3.1 Archaeological approaches to human-environmental interactions

Archaeological studies undertaken by the NIhK aim to review and evaluate the material remains of past human activities within the Jade Bay area. A detailed consideration of archaeological data helps to identify research deficits and serves as a starting point for further investigations. Since many sites are buried under extensive marine sediments, field work is concentrated on sites with favourable preservation conditions and high archaeological significance. One such area in the Western Heete Estuary, Butjadingen, has been examined by archaeological methods in order to reconstruct human-environmental dynamics before and after the Heete intrusion in the 14th century. Archaeological, geological and historical-geographical information is combined and evaluated to carry out targeted surveys by means of archaeological drillings and test-pits (see article of Eichfeld in this volume for a more detailed account).

Further archaeological-geophysical research concerns the issue of former salt peat cutting. The constant demand for salt brought about the invention of a highly specialised technique for the production of salt from peat. This process, called *selnering* (Tys, 2006), was based on the extraction of salt crystals from often flooded peat layers. After drying and burning the peat, the ashes were mixed with sea water. The result was brine with high salinity, which was heated to produce salt. Historical sources describe this procedure since the 13th century. However, regional finds of highly specialised ceramics, called briquetage, suggest that salt peat production had already started in the Early Middle Age or in the Roman Iron Age (Först, 1988; Krämer, 1991; Behre, 2005).

The extensive degradations caused by the digging of peat sods led to a lowering of large parts of the area and thus to a major problem: in the case of a dike failure, water could stream unhindered into these lower levels and remain there for elongated periods. So salt peat cutting probably contributed to the formation of the Jade Bay (Behre, 2008).

Until now we have had no reliable information about the dimension of the *selnering*. Without this knowledge it is impossible to evaluate the role of salt peat cutting in the formation of the Jade Bay. Hence, one aim of the Jade Bay project is to map the salt peat digging areas, which are characterised by their specific sedimentary structure caused by the excavation technique. After evaluation of historical maps and written sources, it is planned to apply geophysical measurements in order to detect and explore *selnering* areas.

3.2 Historical geography and morphodynamical balance

This sub-project focuses on morphodynamic processes and the medieval and post-medieval development of the region, thus refining and consolidating the long-term perspective discussed in chapter 2. This kind of research is carried out by the NLWKN Coastal Research Center and is based on historical sources and landscape reconstructions as proposed by Homeier (1982). It highlights the mutual influence of nature (e.g. of the sea and its storm surges) and people who learned how to defend their land by building dikes. The Jade Bay region has a very eventful history in this regard.

Furthermore, based on maps covering the last 150 years, morphodynamic processes will be reconstructed. The aim is to relate the main factors of Wadden morphodynamics, such as flow velocity, tidal water volume, channel cross sectional area and catchment basin surface (Goldenbogen *et al.*, 1998). Since these variables are closely related to each other, it is possible to see for each period covered by the respective maps whether the system of the Jade Bay was in a phase of morphodynamic equilibrium or in transition (e.g. in an equilibrium state, the channel cross sectional area is directly linked to the tidal water volume of the basin).

4. Natural and anthropogenic dynamics in the tidal zone

Intertidal and subtidal zones are areas of great sedimentological and ecological diversity. Within the scope of the Jade Bay Project, the current chemical and benthic ecological status will be detected and compared with former studies.

4.1 Chemistry

Chemical studies carried out by the ICBM focus on natural and anthropogenic dynamics of inorganic and organic pollutants such as heavy metals, PAH (polycyclic aromatic hydrocarbons), PCB (polychlorinated biphenyls), and TBT (Tributyltin). The current pollution of the sediments and the water column is compared to the degree of pollution determined by former studies (e.g. Schwedhelm and Irion, 1985). The ongoing chemical analyses will further provide information on whether the pollution of the Jade estuary is increased due to the construction of the Jade-Weser-Port.

In surface sediments, chemical studies are combined with benthos analyses to identify whether sediment contaminations have negative effects on the benthos community. The sampling grid covers representative sites of different sediment types and littoral zones. Chemical analyses are further performed on up to 15 m long sediment cores to be drilled along the NE-SW-transect across the Jade Bay (Fig. 2).

4.2 Benthos ecology

The main objective of this sub-project is a comparison between recent data on structure and distribution of macrofaunal communities with investigations carried out in the intertidal by Linke (1939) in the 1930s and Michaelis (1986) in the 1970s, as well as the subtidal by Dörjes *et al.* (1969; 1970) in the 1970s to detect changes in the species composition and in the community structure due to natural or anthropogenic impacts (Fig. 2).

Subtidal stations are sampled with a 0.2 m^2 van Veen grab according to Dörjes *et al.* (1969; 1970). The intertidal stations along several transects covering the whole Jade Bay are sampled with cylindrical cores (10 cm in diameter) according to Linke (1939). Additionally, the structure and distribution of meiofaunal communities as well as sediment composition and chemical components such as inorganic and organic pollutants (see chapter 4.1) are investigated on the same spatial resolution.

To get an insight into the complex interactions between organisms and their environment a further objective will be the study of macrofaunal and meiofaunal activities and their effect on nutrient fluxes in the sediment, sediment reactivity and pore-water distribution.

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Impacts of Human Activities

User limits or natural limits: can we set limits to human use, based on a natural functioning of the Wadden Sea?

M.J. Baptist (martin.baptist@wur.nl)[1,3], N. Dankers[1], C.J. Bastmeijer[2], A.G. Brinkman[1], J.E. Tamis[1], R. Jongbloed[1], F.E. Fey[1], W.E. van Duin[1], C.J. Smit[1], H.J. Lindeboom[1]
[1]Wageningen IMARES, [2]Faculty of Law, Tilburg University, [3]Corresponding author.

Abstract

In The Netherlands, a new policy framework for limiting human use in marine protected areas was proposed in 2004. The framework consists of a system of 'natural limits' for which scientific consensus exist that as long as these limits are not exceeded, natural processes in the Wadden Sea will not be significantly influenced. This proposal produced much discussion as well as confusion concerning definitions. Should we speak of 'natural limits' or rather 'user limits'? Are the limits set by the natural processes of the Wadden Sea, or rather by policy makers? And, last but not least, how do we quantify these limits in the light of the complexity and dynamics of the Wadden Sea ecosystem, and will they stand in legal procedures? In this study we evaluated the feasibility of the proposed framework from an ecological and juridical perspective. We made a distinction between two types of limits, those set by law and policy, such as the EU Habitats and Birds Directives or the trilateral Eco-targets, and those set by ecological knowledge, such as carrying capacity and minimal viable population size. We studied available knowledge and defined limits based on natural processes for salt marshes, mussel beds, bird populations and habitat type 1140 (intertidal areas). Next, we formulated a step-by-step approach for setting limits to human use based on clear definitions for nature types. We studied whether this could lead to spatio-temporally defined user limits agreed upon by policy. We concluded that since the Wadden Sea is highly dynamic, any system of user limits should be made flexible and would require continuous monitoring and a system of adaptive management. We further concluded that a system of generic user limits, valid for all types of activities in all of the Wadden Sea is not feasible. Each proposed plan or activity needs a location specific assessment for which local and overall cumulative effects need to be assessed and weighted; however, scientifically well supported natural limits could substantially support the implementation of the legal system and the final go or no-go decision.

1. Introduction

In 2004, the Dutch Advisory Committee on Wadden Sea Policy suggested a new policy framework to set limits to human use in the Wadden Sea (Meijer *et al.*, 2004). The framework consists of a system of 'natural limits' for which scientific consensus exists that as long as these limits are not exceeded, natural processes in the Wadden Sea would not be significantly influenced. The framework sets limits to human use, based on the premise that in the Wadden Sea natural features stand above human uses. The Committee suggested setting up a generic set of natural limits, valid for the entire Wadden Sea and for all types of activities. Once the limits are established, making the appropriate assessment (according to the EU Habitats Directive) of a new plan or project in the Wadden Sea should be easier.

In 2007, the Dutch Wadden Council (Raad voor de Wadden) published advice on the applicability of natural limits (RVDW, 2007). They gave a definition for natural limits in which human activities play a more prominent role: "*a system of limits for the most important natural parameters, linked to human activities, for which scientific consensus exists that as long as these limits are not exceeded, natural processes in the Wadden Sea would go undisturbed*". The Council concluded that there should be a system of limits to human use, agreed upon by society, for which the effects of human use lie in between minimum and maximum threshold values for significant change of ecosystems (Figure 1).

Various workshops have been held with experts and policy makers in an effort to elaborate on a system of natural limits. However, there has been a lot of discussion and also confusion on definitions. Should we speak of 'natural limits' or rather 'user limits'? Are the limits set by the natural processes of the Wadden Sea, or rather by policy makers? And, last but not least, how do we quantify these limits in the light of the complexity and dynamics of the Wadden Sea ecosystem, and will they stand in legal procedures?

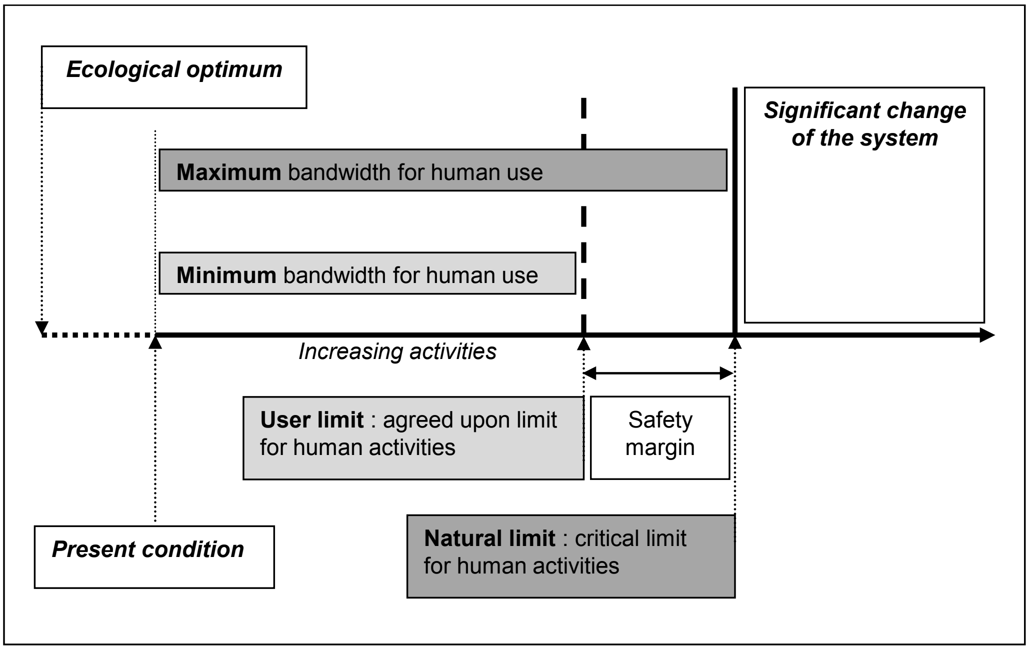

Figure 1: Relational scheme for natural limits and user limits. A natural system has a present condition, which is less than the ecological maximum. For increasing levels of activities, the system moves away from the maximum towards a critical threshold value, beyond which significant change of the system occurs. Two different limits can be defined for human activities. The natural limit, in strict sense, is the critical threshold for significant changes to the natural system. In fact, the user limit is an agreed limit up to which it is certain that no significant changes occur. In between the present condition and the limits, bandwidths of human use can be defined. After Swart and Van der Windt (2007).

In this study the feasibility of the proposed framework is evaluated from an ecological and juridical perspective. Two types of limits were distinguished, those set by law and policy, such as the EU Habitats and Birds Directives or the trilateral Eco-targets, and those set by ecological knowledge, such as carrying capacity and minimal viable population size. For salt marshes, mussel beds, bird populations and EU habitat type 1140 (intertidal areas) available knowledge was studied in more detail and an attempt was made to define limits based on natural processes.

2. Elaboration on natural limits

From analyzing documents and discussion sessions on natural limits we concluded that two main types can be distinguished:

1. Natural limits that follow from political or policy decisions; they are documented in the EU Habitats and Birds Directives, the Water Framework Directive, the trilateral Eco-targets or other documents. They specify minimum areas of habitats, or minimum habitat quality, or minimum size of bird populations needed for a good status of the ecosystem. They have been specified on the basis of ecosystem knowledge, however, they differ from Type 2:

2. Natural limits that follow from ecosystem properties, such as carrying capacity, minimal viable population size or tipping point of a regime shift; they are established on the boundaries of ecosystem components based upon ecological thresholds. Two subtypes can be distinguished:

a. Endogenic natural limits, determined by the boundaries of the range of natural variability within which the ecosystem component exists.

b. Exogenic natural limits, determined by processes and (a)biotic characteristics of environmental variables that serve as boundary conditions to an ecosystem component.

In our view, and in compliance with the definition of the Dutch Advisory Committee on Wadden Sea Policy, Type 2 is the true natural limit or threshold. Therefore, when the aim is to conserve certain ecosystem characteristics, human pressure on the ecosystem should never be so large that this limit is reached and a significant change of the system occurs. In practice, a safety margin is applied, and additional political reasoning will establish limits of Type 1. We suggest that ultimately limits to human use will be defined in such a way that the true natural limits are not exceeded. Conforming with the definition of the Dutch Wadden Council, we prefer to call these limits 'user limits', see Figure 1. An example is gas extraction in the Wadden Sea. Subsidence is the major problem so this activity is allowed as long as it does not exceed the natural sedimentation rate (a Type 2b natural limit) leading to drowning of litoral mudflats (a Type 2a natural limit). In this case the natural sedimentation rate is the natural limit to subsidence and thus to the amount of gas to be extracted. Due to coinciding sea level rise and safety margins the user limit is lower than the natural limit. The gas is extracted with "the hand on the tap"; if limits are exceeded the gas extraction is stopped.

Parameter	Limit.	Type
Size of a salt marsh	Minimum size is 500 ha.	2a
Drainage and ponds	Drainage channels naturally developed and maximum 10% of salt marsh area. Ponds are part of a natural salt marsh, total surface area maximum 6% and maximum size 1250 m2 or wind fetch 80 m.	2a
Optimal distribution of habitat types	H1310 (pioneer) ca. 5-25 % (with cover> 5%) and H1330 (well-developed) ca. 75%.	1
Optimal distribution of vegetation zones	All possible zones have to be present with a distribution of minimum 5% and maximum 40% (at a total of 4 zones) or 35% (at a total of 5 zones).	1
Sediment balance deficit	Maximum sediment balance deficit < 5-15 cm.	2b

Table 1:
Natural limits for salt marshes.

We have elaborated and defined natural limits for a number of ecosystem components in the Wadden Sea, i.e. salt marshes, intertidal sand flats and mudflats, intertidal mussel beds, and food availability for birds and will give examples of Type 1 and Type 2 natural limits, where possible.

2.1 Salt marshes (habitats 1310 and 1330)

Natural limits for salt marshes can be defined for their quantity and for their quality. A certain minimum size is required to have diversity of geomorphology and biotopes, and to give room for processes of natural rejuvenation. Beeftink (1984) defined a minimum size of 500 ha per site, which is a Type 2a natural limit.

The quality of a salt marsh is determined by the relative area of vegetation zones. Dijkema *et al.* (2005a) defined a set of (natural) limits to different vegetation zones to be used for the Water Framework Directive. They state that the relative distribution of each zone should lie between a minimum of 5% and a maximum of 35% (with five vegetation zones) or 40% (with four vegetation zones). Furthermore, climax-vegetation may not dominate (more than 50% cover) within its zone. Together with similar limits for Natura 2000 habitat types, these are examples of Type 1.

Regression from one vegetation type to another can be a natural phenomenon, but two phenomena in particular are unwanted since they will lead to an unstable or unvegetated and therefore potentially erosive situation:

1. regression from a low salt marsh (with sediment stabilizing *Puccinellia*) to a pioneer zone (with *Salicornia*).
2. regression from a pioneer zone to a bare flat.

For the salt marshes of The Netherlands, theoretical lower limits for the height of the marsh (relative to Dutch Ordnance Level) have been defined (e.g. van Duin *et al.*, 1997). These can be viewed as a Type 2a limit: their endogenic natural limits. Due to sea level rise and soil subsidence, the relative height may decrease and unwanted regression may occur. The zonal hypothesis states that a change in vegetation type will occur due to relative sea level rise when the sedimentation rate lags behind. Oost *et al.* (1998) stated that there are no changes in vegetation type when the sediment balance deficit is temporary and smaller than 5 cm. Recent findings showed that in some cases a sediment deficit of as much as 15 cm had no consequences for the vegetation (Dijkema *et al.*, 2005b). The sediment balance deficit for which the salt marsh is still able to exist can be considered as a Type 2b limit: the exogenic natural limit. Research into soil subsidence due to gas extraction on the salt marshes of Ameland has shown that not only the sediment balance, but also the drainage and the grazing management have a profound effect on the vegetation zoning. This makes the definition of generic natural limits more complicated.

Finally, limits have been set for the percentage and maximum size of ponds within saltmarsh systems by Van Duin *et al.* (2003): the total surface area of ponds may not exceed 10% and the size may not exceed 50 x 25 m, or have a maximum wind fetch of 80 m length. These limits have been based on analysis of natural salt marsh systems and are examples of Type 2a limits. A summary of natural limits for salt marshes is presented in Table 1.

2.2 Intertidal sand flats and mudflats (habitat 1140)

Natural limits for H1140 can theoretically be defined for its quantity and for its quality, similar to saltmarshes. Cleveringa and Oost (1999) studied fractal patterns in the tidal basins of the Wadden Sea and defined a minimum tidal volume for sustainable existence of a tidal basin at 55 million m^3. This is a Type 2a natural limit.

Due to relative sea level rise, the hydrography of a tidal basin changes and the basin will attempt to import sediment to maintain an equilibrium state. The rate at which sedimentation can keep up with the rate of SLR is a Type 2b natural limit and is estimated at 5 to 6 mm/year for the Dutch eastern Wadden Sea.

The quality of H1140 is dependent on many abiotic and biotic factors. Natural limits for the quality of H1140 are, therefore, hard to define. Moreover, the natural dynamics in quality parameters such as species abundance, presence of biogenic species or sediment composition are very large. Type 2 natural limits can possibly be defined on the basis of an ecosystem approach in which the ecological functioning of food webs and nutrient cycling form a basis. A conclusive system, however, has not been developed yet. Therefore, only Type 1 natural limits, based mainly on quantity, can be used at this moment.

2.3 Intertidal mussel beds (quality criterion for H1140)

An intertidal mussel bed is defined as: "a benthic community in which mussels (*Mytilus edulis*) are dominant (>5% cover) and in which a spatially well-defined structure of large and small groups of mussels exists, rising above the surrounding sediment and separated by open spaces" (Brinkman *et al.*, 2003). This definition can be seen as a Type 2a natural limit. Compared to salt marshes, the dynamics in structure and shape of mussel beds are highly variable.

Mussel beds exist of mixed age classes that originate from years with successful recruitment. The size and structure of beds are continuously changing due to growth and loss of mussels. The maximum age of mussel beds can range over 10 years (Goudswaard *et al.*, 2006), however, approximately 50% of the area of mussel beds does not become older than 1 year and another 25% does not become older than 2 years (Fey *et al.*, 2008). Older banks show a vertical profile of dead shells, mixed with faeces and pseudofaeces, sand and organic detritus underneath and about 40% live shells on top (Fey *et al.*, 2008; Dankers *et al.*, 2004).

The stability of mussel beds is determined by many factors, such as the age of the bed, the shell-density, the adherence of the byssus-threads, the bed structure, the height of the bed and the stability of the sediment underneath the bed. For the (long-term) survival of mussel beds, many more factors come into play, such as: biological factors (spatfall, recruitment, predation), abiotic factors (inundation period, temperature, salinity, dissolved oxygen, flow velocity, wave exposition, position of the gullies, predominant wind direction). The long list makes it clear that Type 2b natural limits are based on multivariate factors and are hard to define.

2.4 Food availability for bird populations

The quantity of food necessary to support a population of birds can be seen as a natural limit. Such a limit depends upon species, time (period of wintering, moulding, breeding, etc.) and space (roosting areas, food availability nearby, etc.). Furthermore, intraspecific competition plays a role.

At the same time shellfish fishermen harvest mussels and cockles, an important food source for the birds. A major question is: how many shellfish can be harvested annually without creating food limitation for birds. Calculating the natural limits and setting user limits helps to prevent starvation of birds due to exploitation of their food sources.

There are several models that predict the necessary quantity of food for birds (Brinkman *et al.*, 2007). The *generalized functional response* describes the intake rate of food as a function of the density of prey and of competition. Under the assumption of *ideal free* (Fretwell and Lucas Jr., 1970; Sutherland, 1996) behaviour, this leads to predictions on the distribution of birds in their foraging area, the so called *aggregative numerical response* (Van der Meer and Ens, 1997). An important difference must be made between the physiological and the ecological need for food. The ecological need is determined by the amount of food that is physiologically needed and that is available for foraging.

As an example we take the oystercatcher (*Haematopus ostralegus*), which mainly feeds on bivalves. For oystercatchers, Rappoldt *et al.* (2003) found that 3.1 times more food needs to be present in the Wadden Sea than is required for physiological purposes. Wintering oystercatchers need 360 g/day flesh weight of bivalves, a Type 2a natural limit. To support a population of 216,000 birds over a period of 250 days/year (the conservation objective for the Dutch Wadden Sea, a Type 1 limit), a minimum quantity of 0.36 kg/day x 250 days x 216,000 birds x 3.1 (ecological need factor) = 60 million kg flesh weight is needed in total.

By monitoring the annual occurrence of mussel beds and cockles and the number of oystercatchers, both needed and available amount of bivalves can be calculated. If the needed amount is exceeded, shellfish fisheries can be allowed, and from the natural limit calculated above, a user limit can be set and harvested. In principle, such simple natural limits can be derived for more species of shorebirds, however, for many species knowledge is lacking, especially when they feed on a multitude of prey species.

3. Juridical assessment

The Natura 2000 regime requires that conservation targets are set for all sites designated under the European nature protection directives. The targets for a site particularly relate to safeguarding favourable conservation status for species and habitat types for which the site received its European status. The implementation legislation of the Member State must ensure that human activities will only be authorised if, on the basis of an assessment, it is concluded that such activities will not frustrate the conservation targets of the relevant site. In case of uncertainties ('reasonable doubts'), a plan or project may not be authorised.

The development of natural limits fits very well in this system. Particularly if the natural limits are related to the ecological characteristics and qualities that constituted the reason for designating the site, such limits can underpin the implementation of the legal regime. In fact, the natural limits constitute the ecological basis for monitoring ongoing activities and for assessing plans and projects that may affect the site.

A next step - setting user limits for human activities on the basis of natural limits - is to avoid unnecessary assessments, procedures and related costs; however, we conclude that such an approach will almost certainly raise conflicts with the legal requirements. Tailor work (concrete assessments of each plan and project) is required due to various factors, such as the complexity of ecological systems, the requirement to take into account cumulative impacts when assessing the effects of a plan or project, and the required application of the precautionary principle (absence of reasonable doubts). Nonetheless, as stressed above, the natural limits may substantially support such individual assessments and may to a certain extent limit costs because assessments can be based on the already available knowledge regarding natural limits. To have these advantages over a longer period of time, monitoring and continuous research efforts to increase best available knowledge regarding the natural limits are crucial.

4. Implementation of natural and user limits

We defined two main types of natural limits and deduced a third type, that of 'user limits'. To improve the practical use, we propose the following set of definitions:

The *natural limit* is determined by the value(s) for (a) characteristic (environmental) variable(s) at which level a pre-defined ecosystem component or feature complies with its definition. Exceeding the natural limit leads to a significant effect upon the ecosystem component.

The *user limit* is determined by the agreed value(s) for an activity at which level the characteristic (environmental) variables are not significantly affected. Exceeding the user limit may lead to a significant effect upon the ecosystem component.

We propose the following steps when implementing a system of natural and user limits:

1. Define and quantify the ecosystem component and its qualifying variables (its endogenic natural limits).
2. Define the limits of the processes and (a)biotic characteristics of environmental variables that serve as boundary conditions (the exogenic natural limits).
3. Define the limits of external human factors that influence the ecosystem component and may force it beyond its definition (the ultimate user limits).
4. Define the politically agreed limits for human activities in space and time.

User limits can be made flexible in both time and space. The combination of changing environmental and human conditions and flexible user limits can only be managed by a form of adaptive management and monitoring. We therefore propose as subsequent steps:

5. Define monitoring parameters both for ecosystem parameters and human uses.
6. Define flexible user limits by comparing monitored system parameters with natural limits, including natural system dynamics.

5. Conclusions

We conclude that a generic set of natural limits, valid for the entire Wadden Sea and for every activity is not feasible. There are too many intricate and unknown inter-relationships to reach this goal. However, site- and species-specific limits can be defined to enable appropriate assessments for new activities in the Natura 2000 regime. Furthermore, we conclude that knowledge of resilience and uncertainty needs to increase in order to define natural limits and 'significant effects' of activities. We finally recommend application of appropriate monitoring and adaptive management tools in a framework of flexible user limits to support a sustainable balance between human use and nature.

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Does sand extraction near Sylt affect harbour porpoises?

Ansgar Diederichs, Miriam Brandt and Georg Nehls, BioConsult SH, Brinckmannstr. 31, 25813 Husum, a.diederichs@bioconsult-sh.de

Abstract

We conducted a one year investigation between 2007 and 2008 to assess impacts of sand extraction west of Sylt using aerial surveys and passive acoustic monitoring devices (T-PODs). The area was surveyed once every month using a double engine aircraft, and porpoise densities were calculated using distance sampling techniques. Porpoises were present in the area all year round with highest densities (up to 3.5 individuals / km²) and a high number of calf sightings in June and August and much lower densities during the winter months (below 1 ind / km²). This confirms the area's high importance as a breeding ground. Avoidance of the sand extraction site could not be detected on the basis of aerial surveys. Porpoise densities calculated from sightings during aerial surveys increased with distance to the coast; only few porpoises were sighted close to the coast of Sylt where sand extraction takes place, and highest concentrations were found at distances further than 18 km from the shore.

Passive acoustic monitoring devices deployed over a period of 5 months revealed a short term avoidance of the vicinity of the dredging ship by porpoises, possibly due to acoustic disturbance. In comparisons of three reference areas, no significant difference in the long term use of the impact area by harbour porpoises could be detected.

Other studies found fish biomass not to be negatively influenced by sand extraction, and thus the area might not decrease in quality as feeding habitat for porpoises. However, acoustic disturbance by the dredging ship might lead to short term avoidance of the area around the ship with a relatively local and short term effect that cannot be detected by aerial surveys.

1. Introduction

Every year Sylt loses more than one million m³ sand at its beaches along the west coast making coastal protection a necessaty if the island is to be maintained. Therefore sand extraction has taken place during the summer months since 1972 a few kilometres west of Sylt in order to replace sand washed from the beaches. Between 1972 and 2006, more than 36 million m³ sand were extracted (ALR 2007).

At the same time nature protection gained more significance and since 1986 the area was established as a National Park. Due to a high abundance of harbour porpoises and a high proportion of calf sightings the National Park was enlarged to the 12 nm zone west of Sylt and Amrum in 1999 and declared a Special Area of Conservation (SAC) for harbour porpoises. With a size of 1240 km², it was the first whale sanctuary in German waters.

Because the permission for sand extraction ended in 2008, a new application had to be submitted and an Environmental Impact Assessment (EIA) was required. Therefore an investigation of the impacts of sand extraction on harbour porpoises was conducted between June 2007 and June 2008. Possible negative effects of sand extraction on harbour porpoises range from temporal displacement due to noise emission and water turbidity during extraction activities, to a reduction in prey availability and large scale habitat destruction.

Sand was extracted in an approximately 12 km² wide area from 1984 until 2008 (Westerland II, about 13 km west of the city Westerland. The planned extension of the area (Westerland III) contains an area of approximately 55 km² enclosing the area Westerland II (Figure 1).

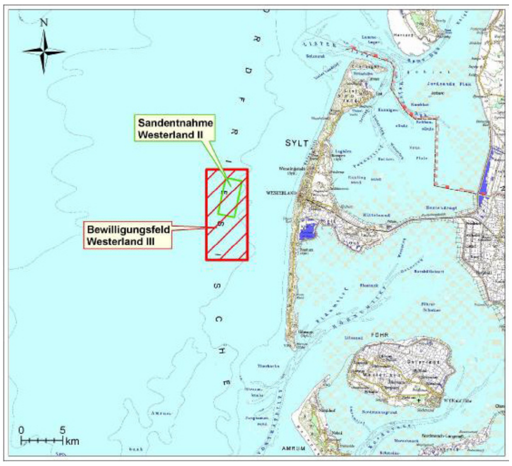


Figure 1: Sand extraction area 1984 – 2008: Westerland II and planned sand extraction area Westerland III.

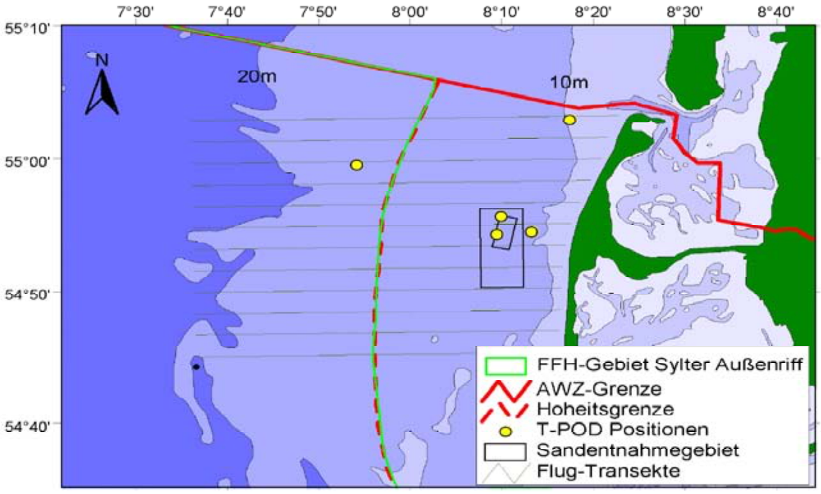


Figure 2: Study area with transect lines for aerial surveys and positions of T-PODs.

2. Methods

In order to gain information on the temporal and spatial scale of the potential effects of sand extraction on harbour porpoise, two different methods were applied. Aerial surveys provide data on the distribution of the animals at a given point in time over a relatively large area with a high spatial resolution. This method also enables us to analyse absolute densities, spatial distribution patterns and the proportion of porpoise calves present in the area.

Passive acoustic monitoring by means of T-PODs provides data with a rather small spatial but a high temporal resolution. Recordings of harbour porpoise clicks show habitat utilization of different areas and can be translated into relative density values. With this method it is possible to detect how long a potential displacement effect might last.

2.1 Arial surveys

Between June 2007 and June 2008, 13 aerial surveys were conducted, with about one survey per month. During each flight 12 parallel transect lines, on average 46 km long and 3 km apart, were flown perpendicular to the coastline and to the depth contours (Figure 2). Total transect length during each flight was approximately 550 km, which represented an area of 1,660 km² covered in one day. The transects started close to the island of Sylt and the area extended into water slightly deeper than 20 m, approximately 50 km west of Sylt.

The aircraft used was a high-winged, twin-engine Partenavia P68, equipped with bubble windows on the rear seats. All survey flights were generally restricted to calm weather and good visibility. Only times which met these criteria were considered valid for further data analysis. Flight altitude was 76 m and the aircraft flew at a speed of 167 to 186 km/h. Three observers searched continuously for animals at the sea surface and recorded their observations with the exact time (synchronised with the GPS-time) on a dictaphone. Recorded parameters were species, group size, presence of calves, swimming direction and behaviour. The position of the aircraft was logged continuously in 3 s intervals by a GPS (Garmin GPS 12CX). Porpoise observations could thus be linked to a specific location.

Data were analysed applying line transect distance sampling (Buckland *et al.* 2001). Beside distribution maps, absolute densities were calculated. For details see Grünkorn *et al.* (2004).

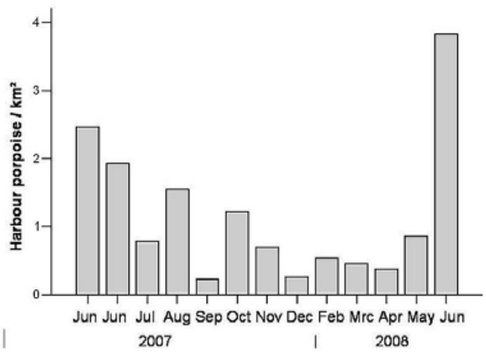


Figure 3: Absolute densities per flight.

2.2 T-PODs

Harbour porpoises orientate under water with short high frequency echo-location clicks. The T-POD takes advantage of this behaviour. The clicks can be recorded with a hydrophone and after presetting different filters, the clicks can be transformed into digital data and saved. The T-POD is housed in a 70 cm long PVC pipe, with

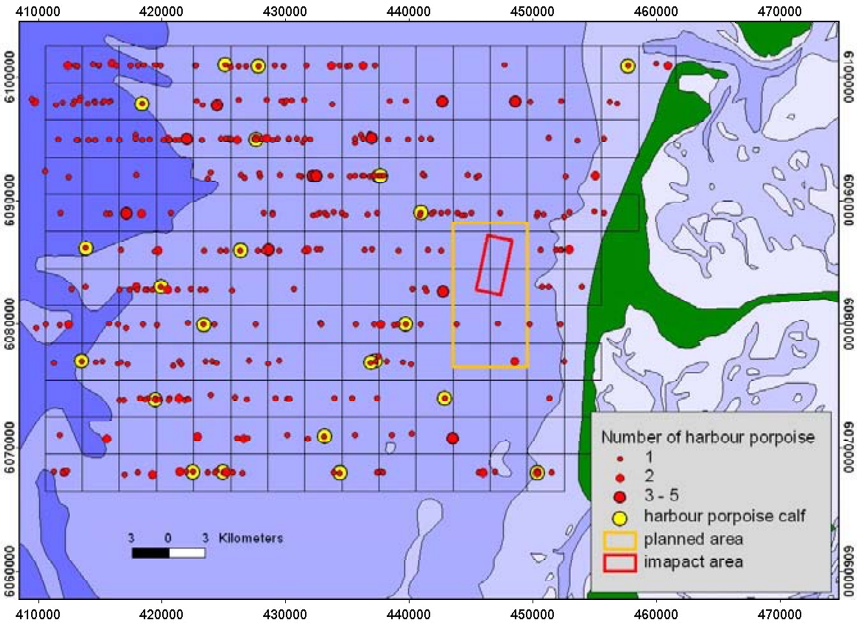


Figure 4: Distribution of all harbour porpoise sightings during all 13 flights from 01.06.2008 until 02.06.2008. Red dots = adult animals; yellow dots

an external hydrophone on one end and a lid screwed on the other. All PODs used in this study were calibrated in a test tank as well as in the field. Recorded clicks were analysed using different parameters. The main parameter is the so-called porpoise positive time per time unit (mostly the number of porpoise-positive 10 minute blocks per day). This parameter was used to measure the presence of harbour porpoises within the detection range of each T-POD.

The T-PODs were deployed with an easily retrievable two-anchor system, in which they were placed two meters above the seabed. The study design was chosen so that two T-PODs were deployed inside the actual extracting area Westerland II, representing the impact area. Two reference positions were chosen, one close to the extracting area (P3) and one a few kilometres north at the same distance to the island as the extraction area. Results of both PODs were combined to "reference area coast". One additional reference position was chosen outside the whale sanctuary approx. 25 km west of the island within the Exclusive Economic Zone (EEZ). This position is called "reference EEZ". All positions are shown in Figure 2. The devices were deployed from June to October 2008.

One position inside the impact area was located within 500m of an area where sand extraction took place during the study period. From this POD, the parameter "waiting time" was analysed in combination with the presence of the sand extraction ship. Waiting time was defined as the time between two consecutive porpoise recordings where the elapsed time was more than 10 minutes.

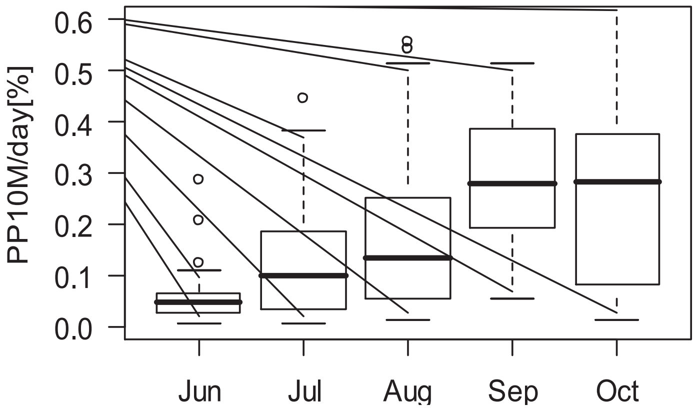
3. Results

Harbour porpoises were observed during every survey. A total of 373 porpoise sightings with 476 individuals were made. Sightings were not evenly distributed over the surveys and showed a distinct seasonal pattern (Figure 3). Most sightings occurred in early summer (June) in both years when densities reached maximum values between 1.9 and 3.8 ind./km². Lowest numbers were observed during winter and early spring (December to April) with densities below 0.5 ind./km².

Calves were observed between June and October (Figure 4). With 11.8% the proportion of calves was highest in June 2007.

Harbour porpoises were observed throughout the study area (Figure 4). Especially during the surveys in June 2007, sightings of porpoises accumulated in the north western part of the study area at a distance of about 25 to 40km to the coastline of Sylt. Densities significantly increased with distance to the coast (r=,09, p<0,01, n=2331, Figure 5). When the study area was divided into two parts (one coastal area up to a distance of 18km to the coastline and one offshore area beyond 18km), densities were significant higher in the offshore area (Mann-Whitney U-Test; $Z_{779,1412}$=-4,49; p<0,01).

Figure 5:
PP10M/day for each month for positions in the impact area.



T-POD data

Porpoise recordings by the T-PODs showed that animals were present at all positions every day. When applying a linear mixed effect model (LMER) including season, distance to coast and sensitivity as fixed factors and the parameter "porpoise positive 10 minutes per day" as dependent factor, there was no significant difference between impact and reference areas (ANOVA, Chi2=0.6863, Df=1, p=0.41).

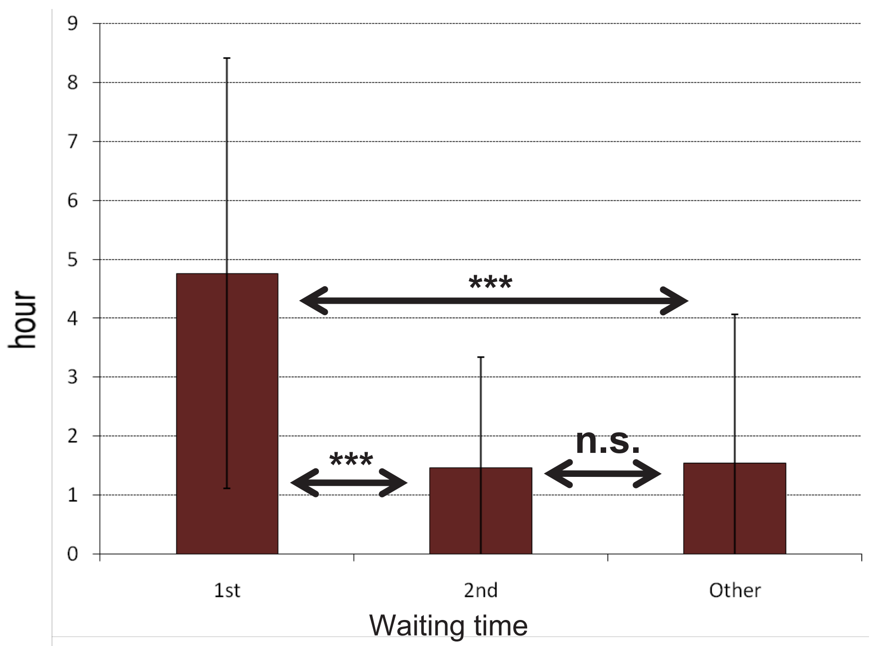
The reference position in the EEZ showed a similar seasonal pattern to that observed during aerial surveys. However, the seasonal pattern observed at the positions close to the coastline showed a differing pattern with highest relative abundance in autumn and lowest in June (Fig. 5).

Analysis of waiting times after the sand extraction ship was closer than 600m to the T-POD location, shows that it took three times longer before a porpoise was again recorded than during times without sand extraction (Figure 6). However, the second waiting time after the ship was gone revealed no differences to those observed during periods without sand extraction.

4. Discussion

The results of this study clearly show that sand extraction did not lead to a long term avoidance of the sand extraction area by porpoises. Aerial surveys could prove that absolute densities increased with distance to the coast. This finding is in line with studies done by Gilles *et al.* (2007), Scheidat *et al.* (2004) and Grünkorn *et al.* (2004). All studies

Figure 6:
Mean waiting time during sand extraction exercises (1st), after the ship left the area (2nd) and when no sand extraction activities tookplace in the area (other).



show highest densities in the Natura 2000 area „Sylt Outer reef" and lower densities close to the coast within the whale sanctuary. However, the high density during summer and high proportion of calves confirms the whole study areas' high importance as a breeding ground.

However, T-POD data showed that the stations close to the coast recorded most harbour porpoise activity during autumn. It is possible that densities close to the coastline follow a different cycle than in the large scale area at a greater distance to the coast. The reason for this remains unclear.

Results of aerial surveys show that the impact area is of lower importance for harbour porpoises than the area further offshore. T-POD data revealed that harbour porpoises used the impact area to the same degree as the surrounding area in a similar distance to the coast. From several studies it is known that harbour porpoises feed on pelagic and demersal fish species (Börjesson *et al.*, 2003, Santos and Pierce 2003, Santos *et al.*, 2004). As other than benthic organisms, pelagic fish are probably not affected by sand extraction, this food resource is probably still available to harbour porpoises even in the impact area.

The only effect of sand extraction on harbour porpoise that could be found was a temporal avoidance of the vicinity of the sand extraction ship for three hours, probably due to sound emission. Noise measurements showed that with 150 dB in 300 m distance from the ship, sound clearly exceeded the hearing threshold of the animals. As this effect is only short and at a very small spatial scale, we conclude that sand extraction has only a minor effect on harbour porpoises.

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Contaminants in Bird Eggs in the Wadden Sea: Trends and Perspectives

Peter H. Becker and Tobias Dittmann, Institut fuer Vogelforschung "Vogelwarte Helgoland"
An der Vogelwarte 21, D-26386 Wilhelmshaven, peter.becker@ifv-vogelwarte.de

1. Introduction

Since 1998, the parameter "Contaminants in Bird Eggs" has been implemented in the Trilateral Monitoring and Assessment Program (TMAP; Becker *et al*., 2001). Each spring, eggs of common tern *Sterna hirundo* and oystercatcher *Haematopus ostralegus* were sampled at 16 breeding sites of the Wadden Sea (Figure 1). In these eggs, concentrations of mercury and organochlorines, including polychlorinated biphenyls (ΣPCB) and some pesticides, were determined (for methods see Becker *et al*., 2001; Becker and Muñoz Cifuentes, 2004).

The previous reviews of spatial and temporal variation (Becker and Muñoz Cifuentes, 2004, 2005) had shown that in the beginning of the 2000s, the Elbe estuary was a hot spot for chemical contamination, and that some pollutant inputs in the western Wadden Sea were obvious. Even if levels of most contaminants had decreased since the beginning of the 1990s and seemed to remain more or less stable in the mid-1990s, concentrations of some substances had increased again in bird eggs, indicating new inputs of pollutants into the Wadden Sea.

In this contribution, we update the information available and evaluate recent levels of contaminants in bird eggs from the Wadden Sea as well as their current trends. We focus on the geographical variation of bird egg contamination from The Netherlands to Denmark in 2008, and on middle-term trends between 1998 and 2008. Furthermore, we present the spatial variation in the concentrations of dioxin-like PCBs, given as toxicological equivalents (TEQs). These TEQs represent the summarized concentrations of 10 from 12 dioxin-like PCBs (Figure 3), each multiplied by a specific toxic equivalency factor (TEF, Van den Berg *et al.* 1998), depending on the toxicity of the substance in relationship to the most toxic substance "dioxin" (2,3,7,8-TCDD) for which TEF is defined as 1.

In addition, we address ecotoxicological aspects and compare the pollutant levels with the Wadden Sea Plan Targets. Ecological Quality Objectives (EcoQOs) concerning the concentrations of mercury and organochlorines in North Sea seabird eggs have been developed by ICES (2003, 2004) and OSPAR (2007). In 2008 and 2009, a pilot project has been carried out to analyze the status of contaminants in bird eggs in the North Sea and to evaluate the proposed EcoQO (OSPAR, 2007). We briefly mention the launch of this pilot project and relate the TMAP findings to the EcoQO.

2. Geographical trends

As in previous years, there were distinct spatial patterns in contaminant levels in both species (Figure 1) in 2008. In common tern eggs, concentrations of mercury, ΣPCB, HCB, ΣDDT and ΣHCH were highest at the Elbe estuary. For ΣPCB, and to a lesser extent also for HCB and ΣDDT, a second spatial peak was recorded at Delfzijl at the Ems estuary.

In oystercatcher eggs, concentrations of mercury, ΣDDT and ΣHCH were highest at the Elbe estuary, those of ΣPCB, HCB and ΣChlordane reached a maximum at the Ems estuary, ΣDDT concentration reached a further peak there. Mercury concentration showed increased values at Balgzand.

These results identify the estuaries of the two rivers Elbe and Ems as the "hot spots" where concentrations of most contaminant groups were highest. In the common tern, peaks of most contaminants were particularly pronounced at the Elbe estuary. In the oystercatcher, this was true for both the Ems and the Elbe estuary. For most pollutants and most sites, contamination was higher in the common tern than in the oystercatcher (Figure 1). Contamination of ΣChlordane, however, was clearly higher in the oystercatcher.

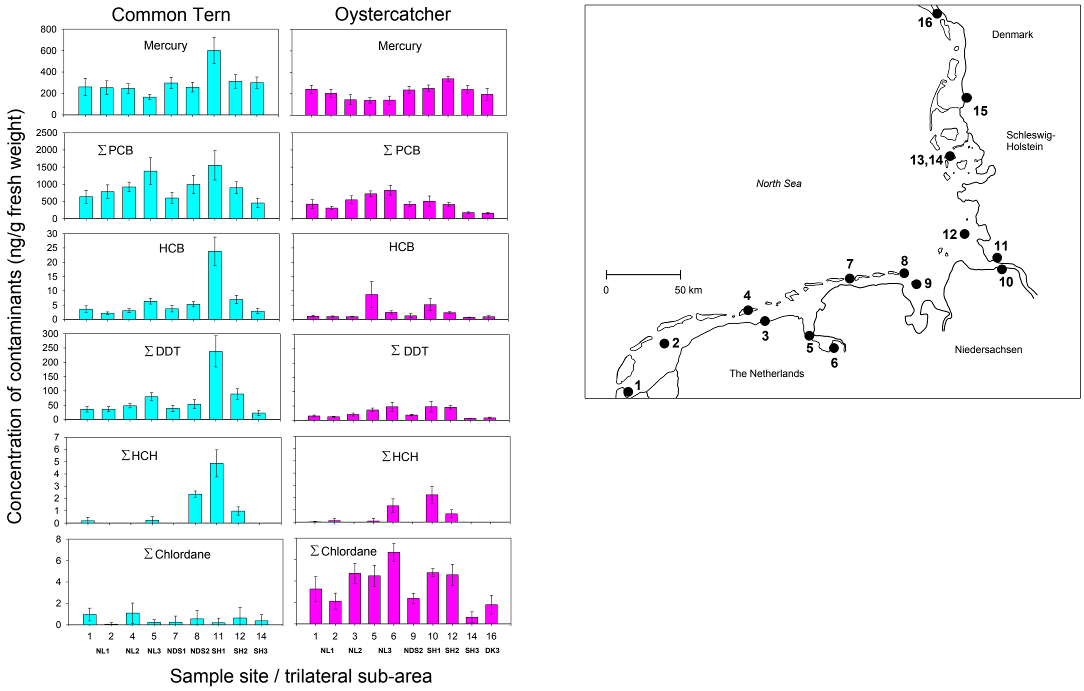

Figure 1:
Spatial variation of the contaminants analyzed in common tern (blue) and oystercatcher eggs (margenta) in 2008 in the Wadden Sea. Mean concentration (ng/g fresh weight of egg content) and 95% confidence intervals are presented for mercury, ΣPCB congeners, HCB, sum of DDT and its metabolites (ΣDDT), sum of HCH-isomers (ΣHCH), and sum of cis- and trans-chlordane and cis- and trans-nonachlor concentrations (ΣChlordane). At most sites, n=10 eggs were sampled. Sampling sites: The Netherlands: 1 Balgzand, 2 Griend, 3 Julianapolder (CT until 2004), 4 Schiermonnikoog (CT since 2005), 5 Delfzijl; Germany, Niedersachsen: 6 Dollart, 7 Baltrum, 8 Minsener Oog, 9 Mellum, 10 Hullen; Germany, Schleswig-Holstein: 11 Neufelderkoog, 12 Trischen, 13 Norderoog (until 2006), 14 Hooge (since 2007); Denmark: 16 Langlie. At the sites 4, 7, 8 and 11, only common tern eggs, at the sites 3, 6, 9, 10 and 16, only oystercatcher eggs were taken; at all other sites, eggs of both species were collected.

3. Temporal trends

An overview of middle-term (1998-2008) trends of contaminant concentrations is given in Figure 2. In oystercatcher eggs, concentrations of HCB, ΣPCB and ΣHCH have significantly decreased (Spearman rank correlation coefficients) at most or all sites between 1998 and 2008. The concentrations of mercury decreased significantly at 7 out of the 10 sites, those of ΣDDT and ΣChlordane did so at 4 of the 10 sites. Significant increases during these 11 study years were recorded for mercury at Trischen, German Bight (r_s=0.272, $p<0.01$, n=110), and Norderoog/Hooge (0.244, $p<0.05$), and for ΣPCB (r_s=0.232, $p<0.05$) and ΣDDT (r_s=0.268, $p<0.01$) at Delfzijl.

In common tern eggs, concentrations of HCB and ΣHCH decreased significantly at most or even all sites. Concentrations of mercury, ΣPCB and ΣChlordane decreased significantly at 4 out of 8 sites. On the other hand, significant increases were recorded for concentrations of ΣPCB (r_s=0.191, $p<0.05$, n=110) and ΣDDT (r_s=0.255, $p<0.01$) at Delfzijl, as in oystercatcher eggs.

4. Ecotoxicological aspects

To date, monitoring of birds' breeding success is not included in the TMAP Common Package. Consequently information on potential differences in hatching success related to contaminants' levels is lacking (cf. Thyen *et al.*, 1998). Muñoz Cifuentes (2004) presented data from the mid 1990s suggesting that the reproductive success of common tern, common gull *Larus canus* and herring gull *Larus argentatus* was negatively affected by organochlorine contamination at the Lower Elbe. The current levels of most contaminants in bird eggs, however, are below the known threshold concentrations affecting birds' reproduction.

As most chemicals, also the TEQ-levels calculated for dioxin-like PCB-congeners (cf. Muñoz Cifuentes, 2004; see 1) showed decreasing trends since 1998 in the Wadden Sea. However, similar to sporadic increases during previous periods, TEQ concentrations in 2008 were elevated in some areas between Dollart and inner German Bight (Figure 3), deviating from the general spatial pattern of ΣPCB (Figure 1). Such TEQ-concentrations are

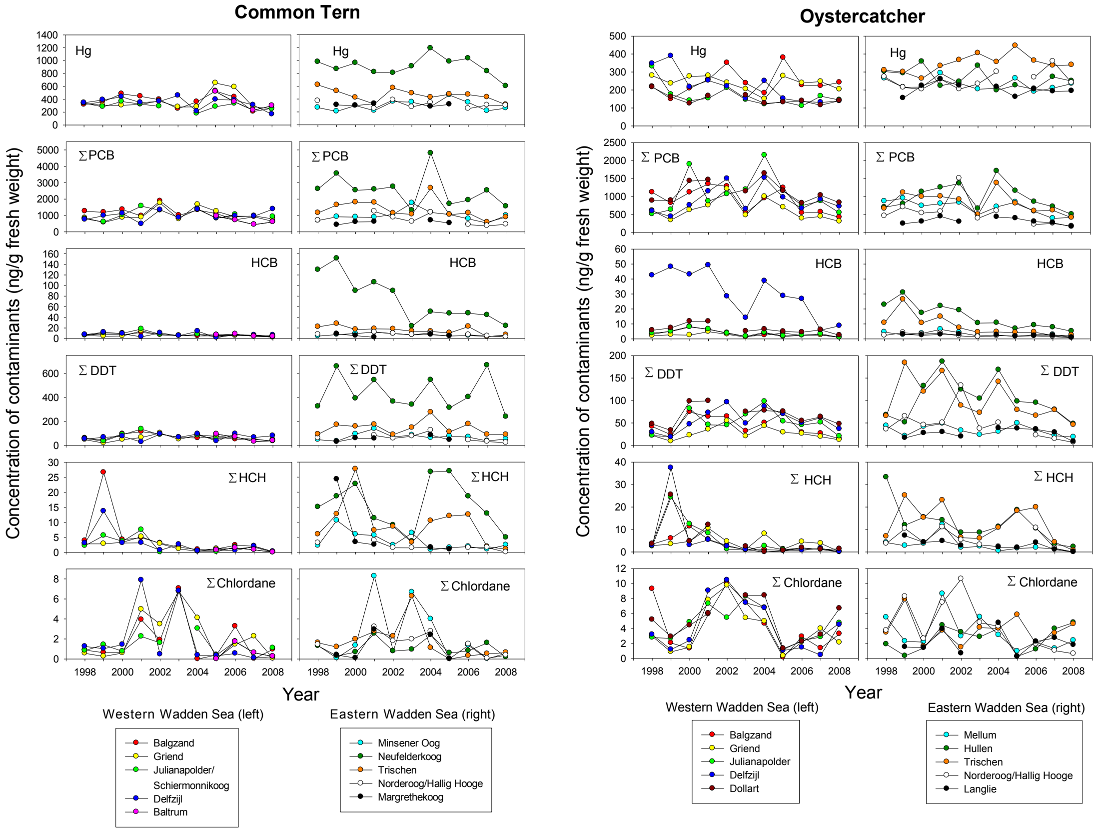

Figure 2: Time trends (1998–2008) of contaminant levels in common tern and oyster-catcher eggs from selected sampling sites (cf. Figure 1). Dots indicate arithmetic means (ng/g fresh weight of egg content; 10 eggs per year, site and species).

in a range where negative effects on the hatchability of fish-eating bird species are reported (90 – 4,000 pg/g, Hoffmann *et al.* 1996). Given a lipid content of 8.2% for the eggs of the study species (Mattig *et al.* 2000), TEQ concentrations recorded were up to about 2,500 times higher than the EU-limits for e.g. chicken eggs destined for human consumption (2 pg/g fat; Chemisches und Veterinärmedizinisches Untersuchungsamt Freiburg 2006).

5. Target evaluation

The concentrations of contaminants measured in bird eggs indicate that the burden of pollutants in the Wadden Sea is slowly decreasing towards the proposed Wadden Sea Plan Targets, which are background concentrations of naturally occurring micropollutants such as mercury, and zero in the case of man-made substances such as organochlorines (TMAP 1997). In 2008, the EcoQOs proposed for contaminants in seabird eggs (ICES 2003, 2004; OSPAR 2007) have already been reached for some substances at some sites in the Wadden Sea. For ΣHCH, this is true at the majority of sampling sites, but not for various other substances and locations (mercury, oystercatcher < 100 ng/g : no site; common tern < 200 ng/g: 1 site; ΣPCB < 20 ng/g: no site in both species; HCB < 2 ng/g: oystercatcher, 6 sites, common tern, no site; ΣDDT < 10 ng/g: oystercatcher, 2 sites, common tern, no site; ΣHCH < 2 ng/g: oystercatcher, 9 sites, common tern, 8 sites).

The stagnation of the levels of various substances and some recent increases point to local problems with environmental pollutants. Among these are several contaminants whose use has been prohibited for several decades. At the hot spots of contamination, the present concentrations of ΣPCB and ΣDDT, especially in the eggs of

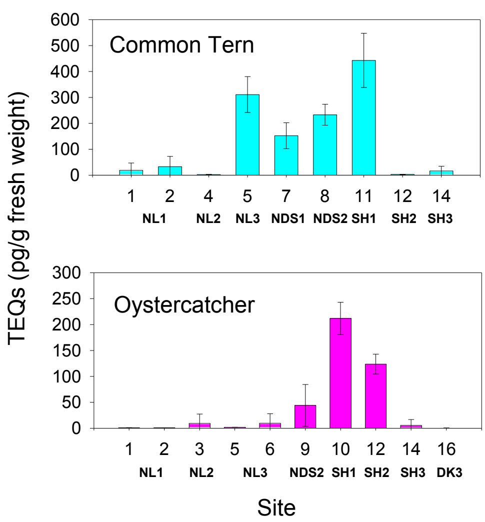

Figure 3: Geographical variation of TEQs (Toxic Equivalents) analyzed in common tern and oystercatcher eggs in the Wadden Sea in 2008 for Non-ortho PCB congeners (PCB126 and 169) and mono-ortho congeners (PCB105, 114, 118, 123, 156, 157, 167 and 189). Mean concentration (pg/g fresh weight of egg content) and 95% confidence intervals are presented. For location of sites cf. Figure 1.

common tern, are still very high in comparison to the target levels.

In the framework of a pilot study on the EcoQO "Mercury and Organohalogens in Seabird Eggs", eggs were sampled at additional sites on the North Sea coast in 2008 (Norway: Rogaland, Sweden: Skagerak, The Netherlands: Rhine-Scheldt estuary, Belgium: Zeebrugge; in 2009 sampling at three sites in the UK is scheduled). The inter-site comparison of contamination levels indicates that, in most cases, concentrations were lowest in the proposed reference areas in Scandinavia which are far distant from industrial hot spots. The tentative EcoQO of mercury ($\leq$100 ng/g in the oystercatcher and $\leq$200 ng/g in the common tern, based on lowest values ever measured in the Wadden Sea) was reached by oystercatcher eggs at Rogaland (97 ng/g) as well as by arctic/common tern eggs at Rogaland and Skagerrak, respectively (173 ng/g). But the lowest ΣPCB-levels found (Rogaland: oystercatcher 132 ng/g, arctic tern 137 ng/g) were still clearly higher than the target level of 20 ng/g.

6. Discussion of trends and conclusions

During the last five years, the Elbe estuary persisted as a hot spot of chemical contamination, although the concentrations of most environmental chemicals were decreasing. By comparison with the previous reports, the Ems estuary has emerged as an additional hot spot (Figure 1). Whereas the formerly elevated HCB levels in oystercatcher eggs have decreased in this area (Figure 2), levels of ΣPCB and ΣDDT have increased in both species studied. In 2008, levels of some contaminants recorded in bird eggs at the Ems estuary were similar or even higher than that at the Elbe estuary (Figure 1). The higher concentrations of all contaminants except ΣChlordane found in common tern compared to oystercatcher eggs may be a result of the higher trophic level and accumulation rates of the common tern.

Since the beginning of the 1990s concentrations of most contaminants have decreased, with some fluctuations in the mid-1990s (Becker *et al.*, 2001). These negative trends did continue during the first decade of the 2000s, with pronounced decreases occurring during the last five years. The results indicate that the general contaminant burden on the ecosystem has lowered. Despite this positive development, the concentrations of some chemicals have increased in recent years, indicating new inputs or remobilization of these substances from sedimentary deposits or by dumping harbour sludge. The increase of ΣPCB and ΣDDT concentrations at the Ems estuary observed in both species is remarkable as these contaminants have been legally banned for decades (see for details Becker *et al.*, 2001).

Contrasting with the general long-term trends, sporadic and partly local events of increased contamination with some substances have occurred since 1998 (Figure 2). The current levels of most contaminants in bird eggs are in general below the known threshold concentrations affecting birds' reproduction. However, the fact that in 2008, TEQs reached biologically relevant levels at some sites shows that the danger of intoxication of birds by environmental chemicals in the Wadden Sea is ongoing, and that even nowadays endangering of bird populations by chemical pollution cannot be excluded.

In 2008, the EcoQOs proposed for contaminants in seabird eggs (ICES 2003, 2004; OSPAR 2007) have already been reached for some substances at some sites in the Wadden Sea. The stagnation of the levels of various substances and some recent increases point to local problems with environmental pollutants. At the hot spots of contamination, the present concentrations of ΣPCB and ΣDDT, especially in the eggs of common tern, are still very high in comparison with the target levels.

7. Recommendations

This well established parameter is effective and fulfils its function as an early warning of chemical pollution of the Wadden Sea and of its top predators. Considering the current contamination status of bird eggs on the Wadden Sea coast and its recent development, we recommend:

(1) to continue monitoring of the TMAP parameter "Contaminants in Bird Eggs" in a long-term perspective, especially at the identified hot spots, and on an annual basis in order to separate short term fluctuations from long-term trends and to use the parameter as an early warning of marine pollution with chemicals;

(2) to include new toxic substances in the analytics;

(3) to carefully supervise the TEQs as an indicator of toxic PCB congeners;

(4) to continue to pursue the one-lab-approach, which, as the basis of the parameter "Contaminants in Birds Eggs" since 1991, saves costs and time;

(5) to continue assessment of the EcoQO "Mercury and Organohalogens in Seabird Eggs" (OSPAR, 2007) in order to supplement the geographical

coverage of “Contaminants in Bird Eggs” by additional sampling sites and reference areas around the North Sea;

(6) to implement the parameter “Breeding Success” within the TMAP, providing a sensitive ecotoxicological indicator. This parameter should be assessed in combination with the parameter “Contaminants in bird eggs ”, at least at the hot spots of chemical pollution (Elbe and Ems estuaries). The combination of both parameters will constitute an effective early warning system against chemical pollution of the Wadden Sea (Thyen *et al.* 1998, Muñoz Cifuentes 2004).

(7) to use the findings as a reminder of the necessity of continuing efforts to reduce anthropogenic atmospheric or riverine inputs of hazardous chemicals into the Wadden Sea, in order to avoid impacts on bird populations and the ecosystem. The elevated concentrations of some PCBs in 2008 in the Wadden Sea are an alert.

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Global warming changes the terrestrial flora of the Wadden Sea

Detlev Metzing, Institute of Biology and Environmental Sciences, University of Oldenburg,
D-26111-Oldenburg, detlev.metzing@uni-oldenburg.de

1. Introduction

Coastal regions are characterized by their high physical and biological diversity and are particularly vulnerable to global change effects (Holligan and Reiners, 1992; Sterr, 1998). Climate change will play a major role for structure, composition and function of coastal ecosystems in future. Plants are essential for structure and function of terrestrial coastal habitats. Coastal development, economic use, biodiversity as stability of dune and salt marsh ecosystems, too, depend on the presence and abundance of particular plant species. Direct (temperature) and indirect (e.g. change of precipitation, sea level rise, wind and water circulation, increasing storm events) consequences of the greenhouse effect will influence distribution patterns of species (and biocoenoses) at different spatial and temporal scales.

Previous studies about the impact of climate change at the coastal ecosystems focus mainly on sea level rise, changed flooding events and therefore on changes of sedimentation and erosion (cf. McLean and Tsyban, 2001). These indirect effects of climate change affect the distribution patterns of plant species and vegetation on a small scale (Metzing, 2006). If we focus on salt marshes, the zonal sequence of plant species is mainly dependent upon duration and frequency of tidal inundations, and hence a shift of vegetation zones towards land (or the dike), in vertical direction to the shoreline, has to be expected. Today the coast is largely embanked, and the dikes limit a shift in this direction. This may result in a loss of salt marsh areas.

Whereas sea level rise will affect the distribution of coastal species on a small scale, a large scale shift of distribution areas (scale > 10^5–10^6 m, Metzing, 2006) is to be expected with climate change, in line with the often displayed correlation of climate and distribution (Pearson and Dawson, 2003). Usually, a northward shift of distribution boundaries accompanies climate warming (Gitay et al., 2002).

Because of the vast climatic gradients, climate change – as changes of temperature and precipitation – will affect distribution of species at a supra-regional scale. This paper describes the potential effect of global warming on the vascular plant flora of salt marshes of terrestrial ecosystems of the Wadden Sea.

2. Approach and methods

213 vascular plant taxa, characteristic for and/or occurring in terrestrial coastal habitats (mainly salt marshes and coastal dunes) of the German Wadden Sea and adjacent areas, were chosen to estimate their climatic sensitivity. Limitation of species numbers was necessary to keep the amount of data manageable. However, the selection is representative of the overall terrestrial flora.

In a first step, the climate variables have been determined. These are closely correlated to plant distribution patterns. Distribution data for the selected taxa have been taken from published distribution maps and other contributions (cf. Metzing, 2005 for sources). Climate data were obtained from the IPCC-Data Distribution Centre (for dataset construction see New et al., 1999) for the period 1961-1990 with a spatial resolution of 0.5° (an area of about 32 x 55 km in the study area). Additional climate indices, such as continentality, aridity, annual mean values, a.o. were calculated from the original data. The relevance of climatic factors for plant distribution patterns was tested by a DCCA in the program CANOCO 4.

In a second step, these climate variables have been used to determine the climatic envelope of each species. This is defined by the climatic space that corresponds to the geographic boundaries within which a plant taxon is considered to grow and reproduce under natural conditions (Box et al., 1993). For a first evaluation of the climatic sensibility of certain plant taxa, the climate envelopes have been plotted, as have the climate ranges of certain geographical areas in diagrams (= ecograms).

Further, the climate envelope model has been used to predict future distribution shifts based on given climate scenarios. Correlation of distribution patterns and climatic data by a niche based model allows prediction of area dislocations caused by climatic change for particular plant taxa. The data have been transferred to GIS (Idrisi), where distribution maps have been drawn for present climate, as well as for the climate change scenarios.

To predict dislocation of distribution areas, two scenarios are used, based on the global model ECHAM4/OPYC3. These have been regionalised by statistical downscaling for the German coasts. According to these scenarios, an increase of annual temperature of 2.5 K and a 15% increase of winter precipitation up to the year 2050 are assumed in the worst case (+ 1.5 K and 7.5%, resp. best case; for temperature, these scenarios equal the B2-mid scenario resp. the A2-high scenario, cf. Hulme and Sheard 1999).

3. Results

A correspondence analysis (DCCA) confirmed the high correlation of temperatures and distribution patterns, while this relationship is less distinct for precipitation. Ecograms based on temperature and precipitation have shown, too, that in comparison to temperature, the precipitation factor is less decisive for the distribution patterns in the Wadden Sea area (this is different for areas with warmer climates and higher aridity, e.g. in the subtropics!). Therefore for further analyses (ecograms, models) precipitation could be neglected, and only temperature variables has been chosen (mean temperature of January, July and year). The combination of January and July temperature includes the factor thermic continentality, defined by a high annual temperature range.

Plotting the climate space covered by a species against the climate space of definite geographical regions allows for a first estimation of whether future climatic conditions will fit the climate envelope of the species. In Figure 1, the climatic space covered by *Leymus arenarius* (Sand Lymegrass; Poaceae) is shown in regard to January and July mean temperature. It is obvious that future climate at the German coast (as predicted by the climate scenario) will result in no overlap with the climatic envelope of *Leymus arenarius* any more.

The ecograms are an appropriate tool for a first estimate of whether the climatic conditions in a given area may be sufficient for a given species even when the climate changes. From this data, the species that are potentially threatened by the predicted climatic changes in a given area can be ascertained. But the ecograms tell us only roughly in which direction dislocations of distribution boundaries will happen. A more detailed idea can be given by modelling the distribution areas, based on the predicted climate change and the climate envelope.

To test the used model, maps based on the climate envelope were also prepared for present climatic conditions. "Present" means the period 1961-1990 of the underlying climatic data. Moreover, it is the same time span in which the used distribution maps were published. An example of *Leymus arenarius* is shown again in Figure 2. It shows the present distribution area of the species in Europe and the modelled species range (climatic envelope shape) for different scenarios. The modelled area reflects the present distribution area quite well. Even for the best case scenario there will be no suitable climatic conditions at the German coast for this species. The worst case scenario predicts a potential loss of *Leymus arenarius* for the Wadden Sea when temperatures increase by 2.5 K, which is predicted in the worst case scenario up to 2050.

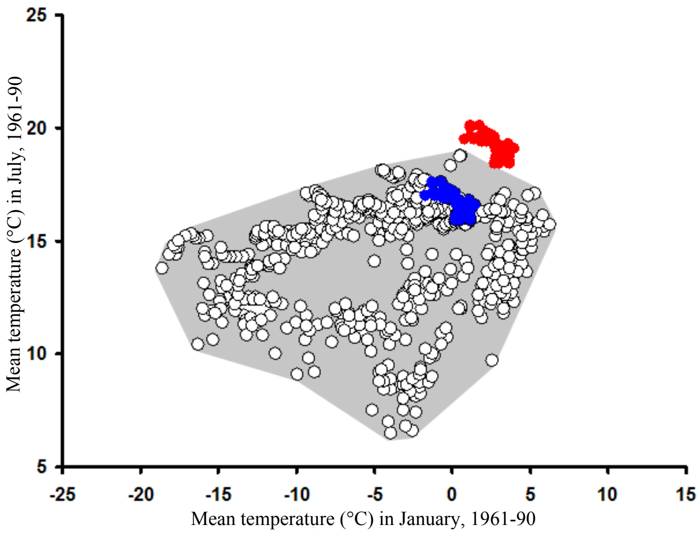

Figure 1: Ecogram of the climatic envelope for *Leymus arenarius* (Poaceae) for January and July temperature. Each point represents climate values of a grid rectangle with a geographical extension of 0.5° x 0.5° where the species is present. The present climatic space (time period 1961-1990) of the German coastal area is indicated by blue spots. The red spots reflect the climate which will prevail at the German coast in 2050 according to the worst-case scenario: 2.5 degree increase in summer and winter temperature. The grey area circumscribes the climate envelope of the species.

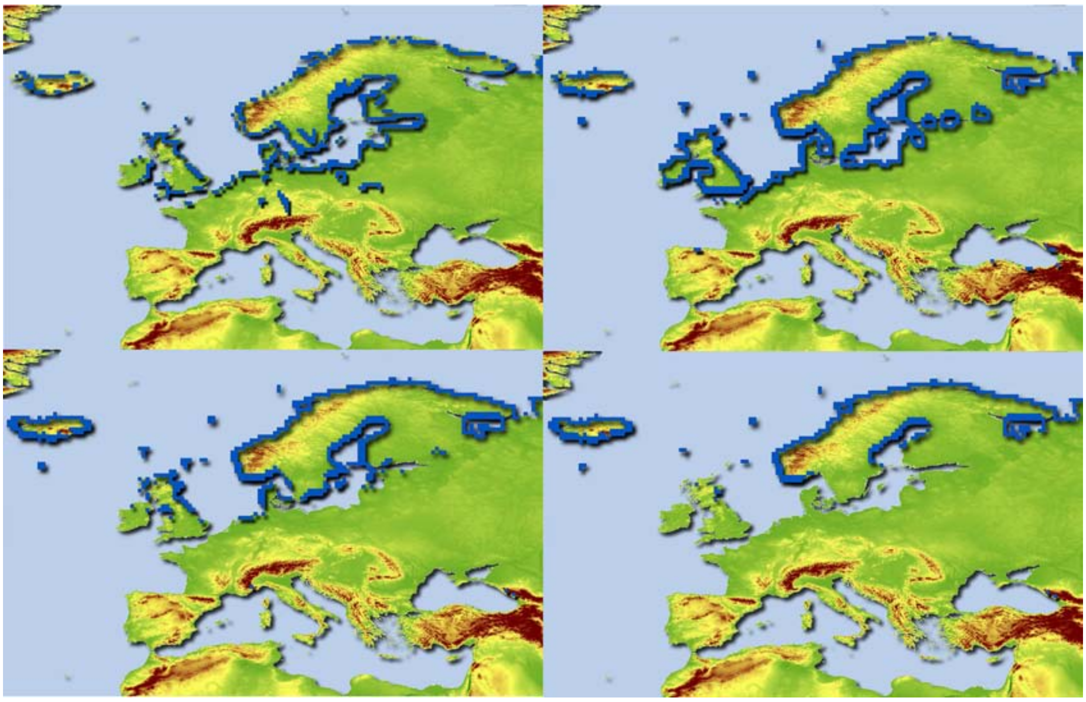

Figure 2: Distribution of *Leymus arenarius* in Europe (top left), modelled distribution range (climatic envelope) along the coast for various scenarios: recent climate (top right), scenario 1 (+ 1.5 K, best case; bottom left), scenario 2 (+ 2.5 K, worst case; bottom right); the distribution area is marked in dark blue.

Climate change will not only affect a loss of biodiversity. Species with a more southerly range may spread into the Wadden Sea area. Such an example may be *Erica cinerea* (Bell heather, Ericaceae). This species is not present at the German Wadden Sea, but grows in dune heaths of the Dutch Wadden Sea islands Texel and Terschelling. According to the analysed data, the winter temperature is the limiting factor at the eastern distribution border. Increasing winter temperatures may allow the species to expand their distribution range eastwards (Figure 3).

Under a high scenario (warming of 2.5 K up to 2050), the climate envelopes for about 55 species (26%) of the species show either an expansion or a reduction within the area of the Wadden Sea coast. About 33 species (16%) of plant species in the Wadden Sea may be lost, according to our model results. There will be a significant impact of climate change on the biodiversity of coastal areas.

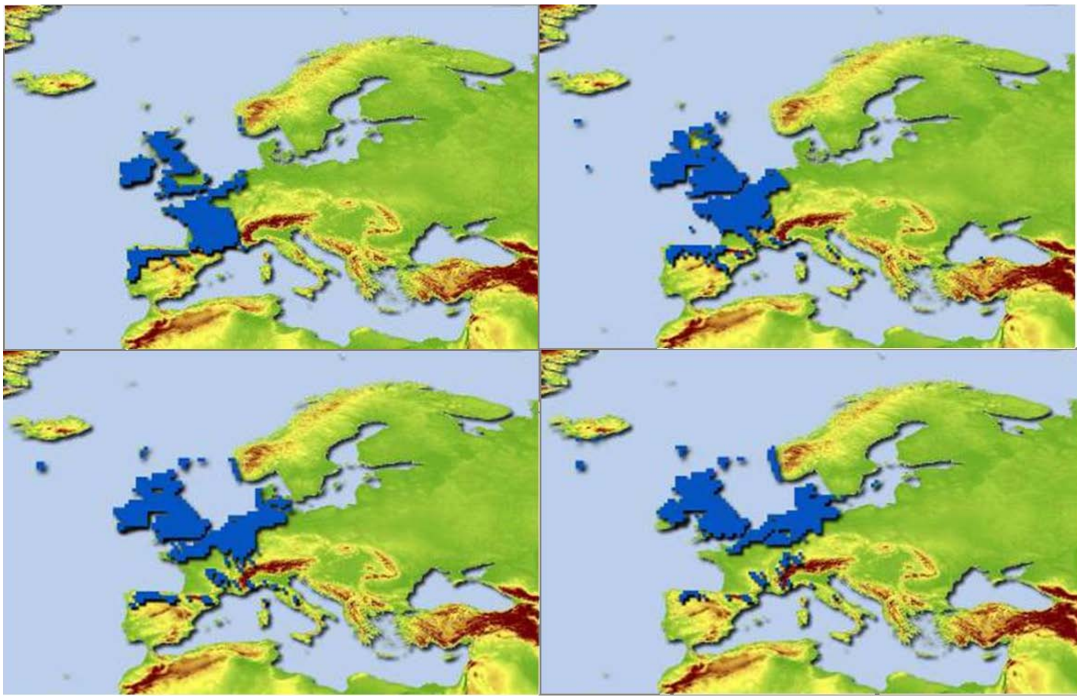

Figure 3: Distribution of *Erica cinerea* in Europe (top left), modelled distribution range (climatic envelope) along the coast for various scenarios: recent climate (top right), scenario 1 (+ 1.5 K, best case; bottom left), scenario 2 (+ 2.5 K, worst case; bottom right); the distribution area is marked in dark blue.

The number of taxa with regressive distribution areas is higher than this of the taxa with progressive ranges. According to this simplified interpretation, we would have to expect a decrease of the total species number, hence a lower phytodiversity (species diversity). But incoming taxa, not present at the German coasts up to now, should also be considered. Where could these taxa – new for the German coastal flora – come from? Coastal areas, which have exactly the same temperature ranges for January, July and the whole year as predicted for the German coast do not exist in Central- and Western Europe. Coastal areas with at least similar climate can be found at the coasts of The Netherlands up to N-France and SE-England. It has to be assumed that coastal taxa predominantly will spread along the coastline to the German coast. The immigration of species from the Mediterranean area or the Black Sea coast would require long distance dispersal across the European continent. This is not impossible, but much less probable (however, the intentional or unintentional introduction of diaspores by men and the transport over long distances may happen and facilitate the establishment of alien plants). Plant species could invade even from inland areas of East- and Central France, but the successful establishment of non-coastal plants in maritime habitats is less probable.

4. Discussion

The models show the direction, distances, and rates of potential distribution shifts which are necessary to stay in equilibrium with climatic conditions. But an inherent characteristic of ecological systems is the delayed response to changing environmental conditions (IPCC, 2002). The real change of distribution patterns will be different for the different taxa, which will react individually and show different migration rates (Huntley, 1991).

Progressive (immigration) and regressive (extinction, emigration) migration have to be distinguished. Whereas immigration is limited by potential dispersal rate and the ability to establish, grow and complete the life cycle in new sites, withdrawal is dependent on delayed mortality and extirpation caused by hardiness and long life-cycles. Generally the colonization of new areas is a lengthy process; hence a delayed response to climate change has to be assumed for most species (Jackson and Overpeck, 2000).

Coastal habitats provide more favourable conditions for dispersal than habitats of other regions, for instance cultivated landscapes, settlement areas, or high mountains. At the coast, most habitats are less fragmented over great distances and are arranged in linear order, so no significant dispersal barriers exist to stop migration along the coast. This is in particular true for the habitats of the drift-lines and salt marshes, less distinct for dunes. Disseminules of many coastal plant species, mainly those of the salt marshes, drift-lines and fore- and yellow dunes, are well adapted to dispersal by sea water and may float over longer time periods and distances (Chang, 2006). On the other hand, plant species strictly confined to coastal habitats can't withdraw to inland habitats if environmental conditions (here: climate) become unsuitable at the coast. However, in general the conditions for progressive distribution shifts are rather favourable at the coast. The way that individual species respond will result in new species combinations, and changed biotic interactions.

In view of the predicted climate change, the climate factor will gain a higher relevance on future plant distribution in comparison with other causes of declining or enlarging distribution ranges (dispersal of neophytes, destruction of habitats, agriculture, land use change). The results of this study allow interpreting and discriminating potential causes of future flora changes.

From the human view, there is a special interest in these species, which play a key role either in the ecology of dunes and salt marshes, or in coastal defense. Such species with a predicted retreat in the Wadden Sea are e.g. *Leymus arenarius* and x *Calammophila baltica*. These species are planted for coastal defense purposes in yellow dunes ("Weißdünen"). *Empetrum nigrum* is another species, where the models predict an extinction in the Wadden Sea up to 2050 (worst case scenario, +2.5 K). The loss of this species will change the appearance and function of brown dunes at the islands conspicuously.

It is more difficult to predict potential immigration than emigration, as potential invaders may come not only from coastal regions, but also from inland. These have been omitted in this study for methodological reasons. The balance of immigration and local extinction will determine a loss or gain of biodiversity. There is no reason to assume that species loss will be retarded by climate change – many studies prove the opposite (Gitay et al., 2002).

For evaluation and optimization of such model predictions it is urgent to establish monitoring projects. e.g. floristic mapping of selected areas or remote sensing of *Empetrum* heaths. Regular monitoring makes it possible to detect future developments and to organize possible management actions. The models show which species are probably most sensitive to increasing temperatures; these taxa may serve as indicator species in monitoring plant species distribution. Moreover, indicator species should be easily identifiable to get sure data. Suitable indicator species are listed in Table 1.

5. Conclusion

The model, based on climate envelopes of the plant species, predicts shifts of distribution ranges within the Wadden Sea area for more than a quarter of the considered taxa. This will change floristic composition and biodiversity remarkably. Some species will be lost, others may immigrate into the Wadden Sea area. A regular and standardized monitoring of the (plant) species inventory (floristic mapping, incl. or only indicator species) is essential to detect realized distribution shifts as well as to verify/optimize models and predictions.

Table 1: Suitable indicator species of climate change in the Wadden Sea area. R = species with predicted regressive distribution areas, P = species with predicted progressive distribution areas

×*Calammophila baltica* (R)
Empetrum nigrum (R)
Lathyrus japonicus (R)
Leymus arenarius (R)
Polygonum maritimum (P)
Euphorbia paralias (P)
Calystegia soldanella (P)
Crithmum maritimum (P)
Cynodon dactylon (P)
Glaucium flavum (P)
Tuberaria guttata (P)
Ulex europaeus (P)
Lagurus ovatus (P)

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